A Low-Complexity and High-Quality Image Compression Method for Digital Cameras

Xiang Xie, Guolin Li, and Zhihua Wang

ABSTRACT—This letter proposes a new near-lossless image compression method with only one line buffer cost for a digital camera with Bayer format image. For such format data, it can provide a low average compression rate (4.24bits/pixel) with high-image quality (larger than 46.37dB where the error of every pixel is less than two). The experimental results show that the near-lossless compression method has better performance than JPEG-LS (lossless) with δ = 2 for a Bayer format image.

Keywords—Near-lossless image compression, Bayer format image, JPEG-LS.

I. Introduction

An efficient image compression with high quality is very important for color video images, especially for medical video images [1]-[3] and wireless image communication with the requirement of high-image quality. Some improved algorithms [4]-[9] called compression-first schemes have been presented and demonstrated, where more pertinent information is retained, so a lower compression rate and higher image quality can be achieved. In [5], a sub-band coding technique is applied to the direct compression of color filter array (CFA) data, Lee and Ortega [6] give a reversible image transformation to compress un-interpolated images with JPEG, and Koh, Mukherjee, and Mitra [7] present two new image compression methods, a 'structure conversion' method and 'structure separation' method with JPEG. Those compression-first schemes with high computational complexity were proposed for lossy compression application and are not suitable for near-lossless and lossless image compression applications, such as in a wireless endoscopy system, which requires very high image quality. Only the low-pass filter of the 'structure conversion' method in [7] can be used for near-lossless compression because it has good reconstruction ability. Therefore, the 'structure conversion' method will be compared with the proposed near-lossless compression method in this letter. This letter proposes a new near-lossless image compression method with low complexity for a digital camera. This compression method has been applied in the wireless endoscopic capsule designed by the authors [3] to reduce the communication bandwidth and transmitting power of image data. Figure 1 shows a simplified block diagram of our wireless endoscopic capsule system. The CMOS image sensor can output Bayer color image data [8]. In the proposed method, the CFA data is first low-pass filtered and then compressed by a lossless image compression coder, JPEG-LS (lossless). It has a very low complexity hardware implementation. In this letter, near-lossless is defined as a PSNR larger than 46 dB where no pixel has an error of more than 2 intensity levels. This strict definition assures a high image quality [9].

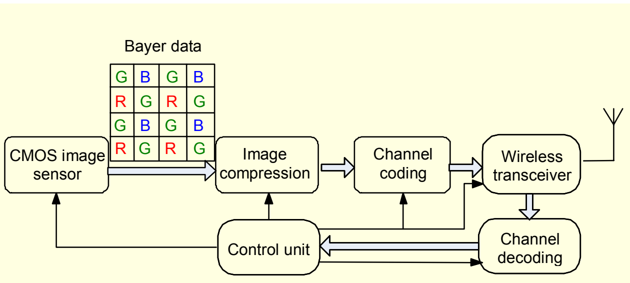

Fig. 1. Simplified block diagram of the system architecture inside the wireless endoscopic capsule.

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II. Proposed Near-Lossless Compression Method

1. Compression Method Description

There are two direct compression methods for Bayer format image data. The first method is to compress Bayer data directly, and the other is to compress G, B, and R components as shown in [4]-[9]. The proposed compression method belongs to the first method. From the viewpoint of compression performance, the second method is better than the first method. However, the second method needs a greater additional buffer with a half-image size to store the R and B components than the proposed method when G components are being compressed. In our wireless endoscopy system [3], the captured image size is 640 × 480 × 8 bits and the designed endoscopic capsule size is smaller than 10 mm × 25 mm. Even if we use the 0.18 μm CMOS process, RAM with 640 × 480 × 8 × 0.5 bit size is too large to be installed in the endoscopic capsule. So, the proposed method with one line buffer is applied for this system.

A simple structure of the proposed near-lossless compression method is illustrated in Fig. 2. A low-pass filter is used before image compression. JPEG-LS (lossless) is used here for low complexity of hardware implementation. The specified region of interest (ROI) can be coded without loss by adjusting the ROI parameters. The corresponding decompression algorithm is shown in Fig. 2(b). It is a simple reverse procedure of the compression.

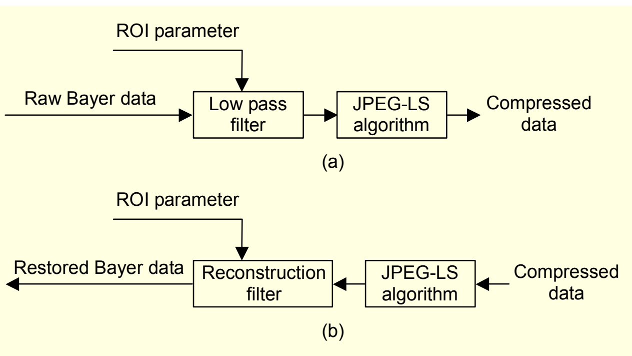

Fig. 2. Block diagrams: (a) The proposed near-lossless compression algorithm and (b) corresponding decompression algorithm.

All the pixels except those in the first row are filtered row by row as illustrated in Fig. 3. The low-pass filter is described in (1).

$$\begin{aligned} (2,1) &= \big((1,1) + (1,1) + (1,2) + (2,1)\big) / 4 \\ (2,2) &= \big((1,1) + (1,2) + (1,3) + (2,2)\big) / 4 \\ &\vdots \\ (3,1) &= \big((2,1) + (2,1) + (2,2) + (3,1)\big) / 4 \\ &\vdots \\ (m,n) &= \big((m-1,n-1) + (m-1,n) + (m-1,n+1) + (m,n)\big) / 4 \\ &\vdots \end{aligned} \quad (1)$$

Note that the filtering operation is different from the conventional one. The low-pass filter scans from the second row until the last row is reached. The virtual pixel of the left boundary is equal to its nearest right pixel in the first column, and the virtual pixel of the right boundary is equal to its nearest left pixel in the last column. Those virtual pixels are used to compute left and right boundary points in the filtering operation. The circled number represents the scan sequence of the filter operation. Note that in this compression method, one row of the filtered pixels will be stored for the filtering operation of its next neighboring row. From the viewpoint of hardware implementation, one line buffer is needed to store one row of values of the filtered pixels. After the filtering operation, the Bayer data arrays will become smoother. Thus, the compression rate can be improved.

The reconstruction filtering operation can be illustrated as in (2) and Fig. 4.

$$(m,n) = 4 \times (m,n) - (m-1,n-1) - (m-1,n) - (m-1,n+1) \quad (2)$$

2. Lossless Compression of ROI

In the proposed near-lossless compression method, the processing of the ROI is very simple. The lossless compression of the ROI is realized in such a way that the pixels in the ROI are not filtered by the low-pass filters according to the ROI

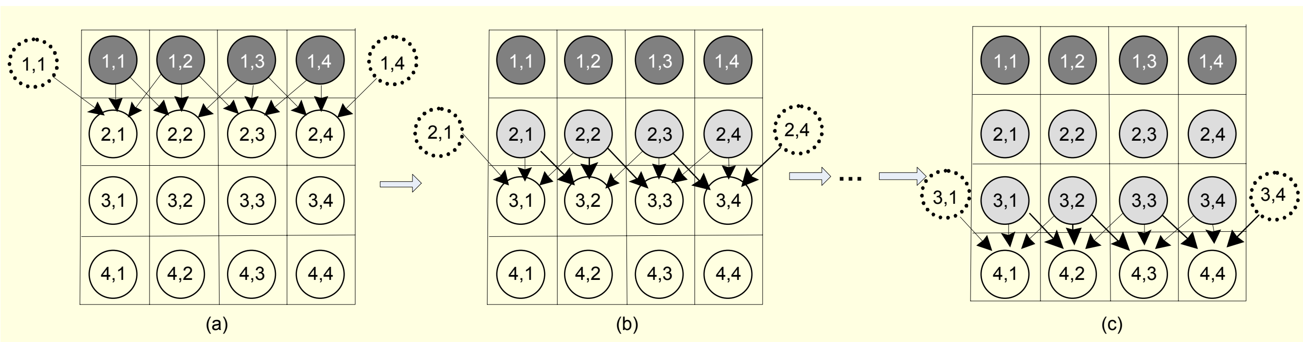

Fig. 3. Smoothing by filtering operation.

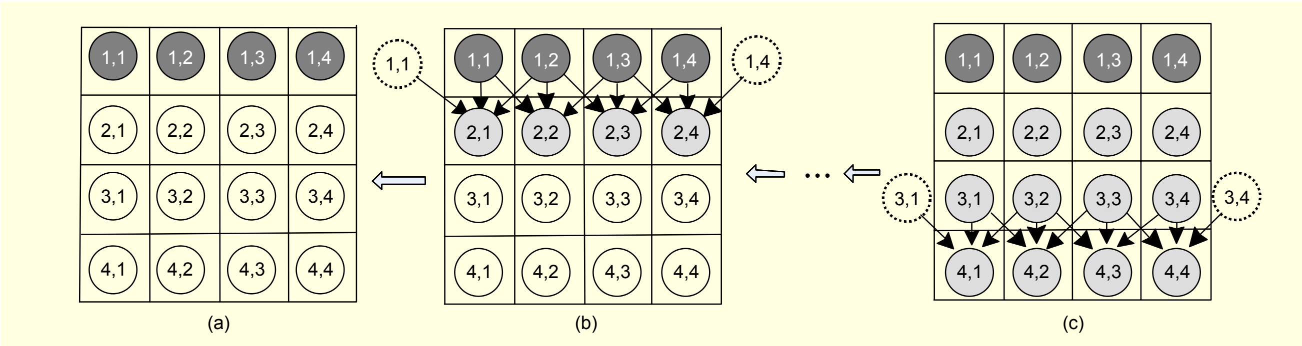

Fig. 4. The reconstruction filtering operation.

G11	B12	G13	B14	G15	B16	G17	B18
R21	G22	R23	G24	R25	G26	R27	G28
G31	B32	G33	B34	G35	B36	G37	B38
R41	G42	R43	G44	R45	G46	R47	G48
G51	B52	G53	B54	G55	B56	G57	B58
R61	G62	R63	G64	R65	G66	R67	G68
G71	B72	G73	B74	G75	B76	G77	B78
R81	G82	R83	G84	R85	G86	R87	G88

Fig. 5. The ROI is in the 2 × 2 dashed rectangle.

parameters that contain the information of location and shape of the ROI. For example, in Fig.5, assuming that the size of CFA data is 8 × 8 and the ROI is in a 2 × 2 dashed rectangle, the pixels in dashed rectangle, G44, R45, B54, and G55, are not filtered, which means that the pixels in the specified ROI are compressed without loss. In the application, the ROI can be selected by a doctor through a computer outside the capsule because the designed wireless endoscopy is a half-duplex wireless communication system [3].

3. Rounding Operation

The coefficient in (1), 1/4, makes a division operation or shift operation unavoidable in the filtering operation. Its residual values are 0, 1, 2, or 3. To reduce the residual error, a rounding operation is applied. It is described simply as

$$y = \left\lfloor \frac{1}{4}(x+1) \right\rfloor. \tag{3}$$

Here, $\lfloor \bullet \rfloor$ is the floor function which returns the greatest integer less than or equal to $\bullet$, and x and y are integers. After the rounding operation, the absolute error, e, between the original data and filtered data can be described in (4). The maximum absolution error is reduced to two, that is, $e \le 2$.

$$e = \left| x - 4 \times \left\lfloor \frac{1}{4} \times (x+1) \right\rfloor \right| \tag{4}$$

According to the statistics of a large amount of images, the approximate probability distribution of e, $p(e)$, can be obtained as

$$p(0) = p(2) = \frac{1}{4}, \quad p(1) = \frac{1}{2}. \tag{5}$$

In this letter, we define the peak signal-to-noise ratio (PSNR) in the near-lossless compression, the measure of image quality, as

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{255^2}{\frac{1}{H \times W}\sum_{x=1}^{W}\sum_{y=1}^{H}(I_1(x,y) - I_2(x,y))^2} \right), \tag{6}$$

where I_1 and I_2 are the original and reconstructed images with a height of H and width of W. They are expressed in integer values between 0 and 255. The locations of the pixels are x and y.

From (5) and (6), we can obtain the PSNR of the reconstructed CFA data as

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{255^2}{\frac{1}{H \times W}\cdot\left[p(1)\cdot(H{\times}W)\cdot 1^2 + p(2)\cdot(H{\times}W)\cdot 2^2\right]} \right) = 46.37. \tag{7}$$

III. Results

The performance of the presented near-lossless compression method is evaluated by comparing it with the JPEG-LS near-lossless compression with near-parameter δ = 2. In this experiment, the Bayer CFA raw data are generated from the

Table 1. Compression results for seven test images.

	Image (512×512)	Airplane	Baboon	House	Lake	Lena	Peppers	Splash	Average
Proposed algorithm	PSNR (dB)	46.403	46.390	46.374	46.387	46.384	46.460	46.464	46.409
	CR (bits/pixel)	3.191	4.892	4.067	4.038	4.712	4.895	3.915	4.244
JPEG-LS lossless	PSNR (dB)	∝	∝	∝	∝	∝	∝	∝	∝
	CR (bits/pixel)	4.707	6.881	5.239	5.912	5.3632	5.314	4.568	5.426
JPEG-LS near-lossless (δ=2)	PSNR (dB)	45.171	52.380	45.154	45.133	45.123	45.241	45.267	46.209
	CR (bits/pixel)	3.012	6.693	3.932	4.408	4.895	5.237	4.872	4.721
Structure conversion method	PSNR (dB)	49.438	49.383	49.377	49.418	49.338	49.611	49.579	49.449
	CR (bit/pixel)	4.583	6.307	5.088	5.671	5.305	5.246	4.217	5.202
G,B, and R respective compression method	PSNR (dB)	46.416	46.391	46.432	46.401	46.409	46.552	46.537	46.448
	CR (bits/pixel)	3.566	5.078	3.922	3.909	4.004	4.056	3.293	3.975

Note. CR means compression rate and ∝ means infinity.

seven standard 24-bit color test images with size 512×512. Table 1 illustrates the comparison results.

Among the compression algorithms in Table 1, except the first compression method, namely the G, B, and R respective compression method, the proposed algorithm can provide the lowest average compression rate (bit/pixel) as well as a high PSNR of larger than 46.37dB. The average compression rate is 4.24 bits/pixel in seven standard test images. Note that the structure conversion method in this table is realized according to the structure conversion method presented in [7] and JPEG-LS (lossless) is used instead of JPEG in this method. The average compression rate of the proposed method has an 18% gain over the structure conversion method. Compared to the JPEG-LS near-lossless compression with $\delta = 2$, the new compression method improves the compression rate by about 15%, as well as having a larger than 1.2 dB gain of PSNR. The average compression rate of the proposed compression method is only 0.269 bits/pixel higher than that of the first method. So, considering the trade-off between the compression rate and the required buffer size, the proposed compression method is more suitable for our wireless endoscopy system.

IV. Conclusions

A low-complexity and high-efficient near-lossless image compression method with low memory cost suitable for a hardware design based on the Bayer format image has been proposed. The average compression rate can reach 4.24 bits/pixel with a PSNR larger than 46.37dB. No pixel has an error of more than 2 intensity levels. The experimental results show that the near-lossless compression method has better performance than JPEG-LS with $\delta = 2$ for Bayer format images. The near-lossless image compression method is suitable for on-chip CFAs of a digital image sensor with low-power and high-image quality. It has been applied in our wireless endoscopy system to reduce the communication bandwidth and the transmitting power of the image data and can also be applied in other medical image fields.

References

[1] Butner, S.E and Ghodoussi, M, "Transforming a Surgical Robot for Human Telesurgery," *IEEE Trans. on Robotics and Automation*, vol. 19, iss. 5, Oct. 2003, pp. 818 – 824.

[2] ddan G, Meron G, Glukhovsky A, Swain P, "Wireless Capsule Endoscopy," *Nature*, vol. 405, 25 May 2000.

[3] Zhihua Wang, Xiang Xie, Chun Zhang, Baoyong Chi, Guolin Li, Li Zhang, and Domgmei Li, "IC Design for a Digital Wireless Endoscope Capsule System," *Proc. Radio Science Conf.*, 2004 Asia-Pacific, Aug. 2004, pp. K42 - K43.

[4] Tsai, Y.T.,"Color Image Compression for Single-Chip Cameras," *IEEE Trans. Electron Devices*, vol. 38, iss. 5, May 1991, pp. 1226-1232.

[5] T. Toi and M. Ohita, "A Subband Coding Technique for Image Compression in Single CCD Cameras with Bayer Color Filter Arrays," *IEEE Trans. Consumer Electronics*, vol. 45, no. 1, Feb. 1999, pp. 176-180,

[6] S.Y. Lee and A. Ortega, "A Novel Approach of Image Compression in Digital Cameras with a Bayer Color Filter Array," *Proc. IEEE Int'l. Conf. Image,* vol. 3, Oct. 2001, pp. 482-485.

[7] Chin Chye Koh, Jayanta Mukherjee, and Sanjit K. Mitra, "New Efficient Methods of Image Compression in Digital Cameras with Color Filter Array," *IEEE Trans. Consumer Electronics*, vol. 49, no. 4, Nov. 2003, pp. 1448-1456.

[8] B.E. Bayer, "Color Imaging Array," U.S. Patent 3,971,065, 1976.

[9] S. Battiato, A. Buemi, L. Della Torre, and A. Vitali, "A Fast Vector Quantization Engine for CFA Data Compression," *Proc. of IEEE-EURASIP, NSIP 2003*, Grado, Italy, June 2003.

[10] Xiang Xie, GuoLin Li, ZhiHua Wang, Chun Zhang, DongMei Li, and XiaoWen Li, "A Novel Method of Lossy Image Compression for Digital Image Sensors with Bayer Color Filter Arrays," *IEEE Int'l Symp. Circuits and Systems Proc. (ISCAS'05)*, Japan, 2005.