An Improved YEF-DCT based Compression Algorithm for Video Capsule Endoscopy

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***Abstract*— Video capsule endoscopy is a non-invasive technique to receive images of intestine for medical diagnostics. The main design challenges of endoscopy capsule are accruing and transmitting acceptable quality images by utilizing as less hardware and battery power as possible. In order to save wireless transmission power and bandwidth, an efficient image compression algorithm needs to be implemented inside the endoscopy electronic capsule. In this paper, an integer discrete-cosine-transform (DCT) based algorithm is presented that works on a low-complexity color-space specially designed for wireless capsule endoscopy application. First of all, thousands of human endoscopic images and video frames have been analyzed to identify special intestinal features present in those frames. Then a color space, referred as YEF, is used. The YEF converter is lossless and takes only a few adders and shift operation to implement. A low-cost quantization scheme with variable chroma sub-sampling options is also implemented to achieve higher compression. Comparing with the existing works, the proposed transform coding based compressor performs strongly with an average compression ratio of 85% and a high image quality index, peak-signal-to-noise ratio (PSNR) of 52 dB.**

I. Introduction

Wireless (or video) capsule endoscopy (WCE) is a non-invasive technique to receive images of gastrointestinal (GI) tract for medical diagnostics [9]. Here a patient ingests a specially designed electronic capsule which has imaging and wireless circuitry embedded inside. While the capsule travels through the GI tract, it captures images and sends them wirelessly to an outside data recorder unit. Later the data are transferred to a personal computer (PC), where the images are displayed. WCE offers a better alternative than the commonly used wired endoscopy by making the procedure more comfortable and efficient. The main design challenges of endoscopy capsule are accruing and transmitting acceptable quality images by utilizing as less hardware and battery power as possible. In order to save wireless transmission power and bandwidth, an efficient image compression algorithm needs to be implemented inside the endoscopy electronic capsule. In this paper, an integer discrete-cosine-transform (DCT) based image compression algorithm is presented that works on a low-complexity color-space converter, referred as YEF, that is specially designed for endoscopic image compression. A low-cost quantization scheme with chroma sub-sampling is also implemented to achieve higher compression. Compared with existing works, the proposed algorithm shows better performance in terms of compression ratio and image quality.

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II. Proposed Algorithm

The compression algorithm has main four steps: color-space conversion, sub-sampling, integer discrete cosine transformation (iDCT), and coefficient quantization. The block diagram of the proposed image compressor is presented in Fig. 1. Each stage is briefly described below.

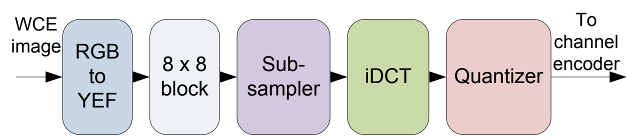

Figure 1. Block diagram of the proposed image compression algorithm

A. RGB to YEF color-space conversion

At this first stage of the algorithm, RGB pixels are converted to the YEF color space [1]. The color space is designed by analyzing the unique properties of endoscopic images for better compression. In YEF, the luminance is stored in Y component, E stores the difference between luminance and green component, and F stores the difference between luminance and blue component. The relationships are shown in (1), (2) and (3).

$$Y = \frac{R}{4} + \frac{G}{2} + \frac{B}{4} \tag{1}$$

$$E = \frac{Y}{2} - \frac{G}{2} + 128 = \frac{R}{8} - \frac{G}{4} + \frac{B}{8} + 128 \tag{2}$$

$$F = \frac{Y}{2} - \left(\frac{3B}{8} + \frac{G}{8}\right) + 128 = \frac{R}{8} + \frac{G}{8} - \frac{B}{4} + 128 \tag{3}$$

In Fig. 2(a), the 3D plots of all component values (i.e., red, green and blue) for different pixel positions of an endoscopic image are shown. From these plots, it can be seen that in RGB plane, the changes in pixel values are high, which means that there is more information contained in the three components. Fig. 2(b) shows the intensity distribution after converting to YEF. It can be seen from Fig. 2(b) that there is less change in pixel values in chrominance components (E and F), which indicates that less information is contained there. Thus these two planes can be compressed and heavily sub-sampled without losing image quality.

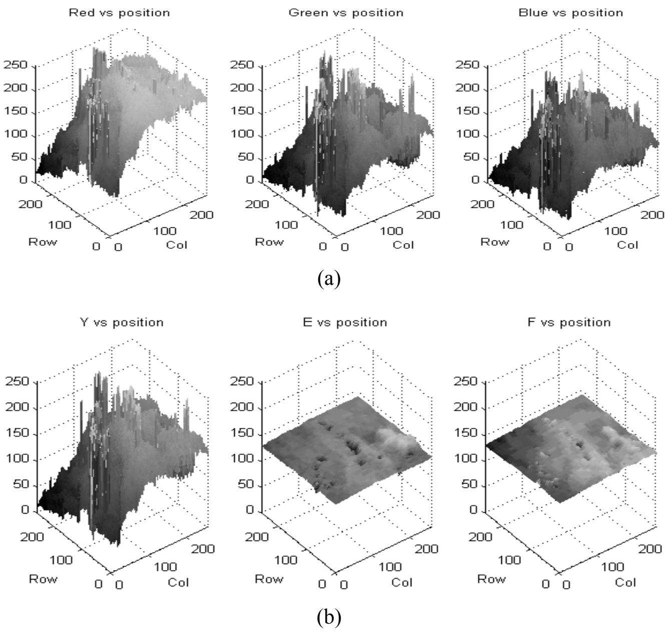

Figure 2. Intensity distribution of an endoscopic image: (a) R, G, and B components; (b) Y, E and F components

From (1), (2) and (3), it is observed that the conversion between color spaces involves only a few additions and divisions by numbers that are powers of 2, which can be implemented by shift operations in digital hardware. Note that, the proposed color space does not neglect the chrominance information. The YEF color space is just another representation of the RGB color space which is more suitable for compression and theoretically lossless. YEF color components can be converted back to RGB color components using (4), (5), and (6).

$$R = Y + 3.33 \times (E - 128) + 2.67 \times (F - 128) \quad (4)$$

$$G = Y - 2 \times (E - 128) \quad (5)$$

$$B = Y + 0.67 \times (E - 128) - 2.67 \times (F - 128) \quad (6)$$

B. *Sub-sampling*

As mentioned earlier, more information is contained in Y component than the chrominance components. In addition, the endoscopic images are analyzed by human doctors visually. The eye is sensitive to small changes in intensity (Y) but not to small changes in color. Thus, losing information in the E and F components compresses the image while introducing distortions to which the eye is not sensitive [15]. In this work, we have used YEF844 sub-sampling. In YEF844, Y component is unaffected; for E and F, only four alternate columns are sampled for every 8 × 8 block as shown in Fig. 3.

C. *Integer Discrete Cosine Transform*

To reduce the power consumption of the capsule, endoscopic images are compressed before transmission. Good quality of reconstructed images can be achieved by using DCT-II [2]; but due to high cost of implementation, the DCT-II is not a good option for the WCE applications. As a result, the integer-based forward DCT is used here. We have investigated several low-cost 8x8 iDCT algorithms. The results (avg. PSNR and cost of implementation) are shown in Table I. It can be seen from Table I that, the iDCT defined in VC-1 produces the best results. Hence, we have chosen it in our implementation.

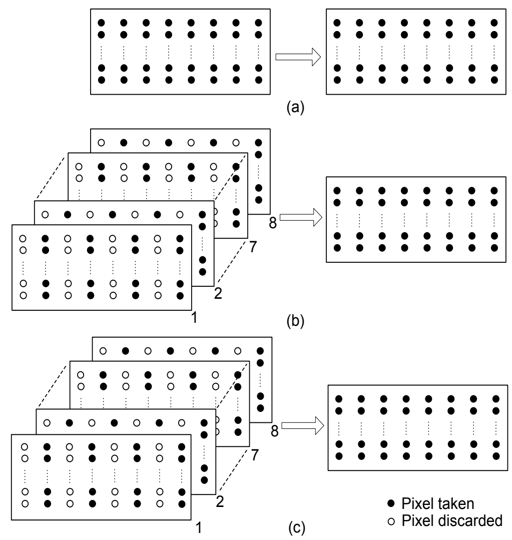

Figure 3. (a) Y component without sub-sampling; (b) sub-sampling of E component; (c) sub-sampling of F component

TABLE I. COMPARISONS OF DIFFERENT 8X8 IDCT

iDCT Scheme	PSNR (dB)	Hardware Cost	
		Adder	*Shifter*
BinDCT [3]	39.25	28	9
BinDCT [4]	38.10	30	13
H.264	38.79	18	17
AVS China	39.57	20	17
VC1 [5]	40.64	18	20

D. *Quantization*

The next step is to find an optimum quantization matrix (in short, Q-table) for three color components (Y, E, and F). Based on the properties of the endoscopic images, two different Q-tables are proposed – one for the luminance and one for the chrominance components. It should be reiterated that among the three components, Y holds the most important information (brightness). Taking this consideration into account, we have chosen the parameters of the Q-tables: the coefficients in the Q-table for Y are smaller than the chrominance components. The Q-tables are shown in Tables II and III.

The entries in the Q-tables are smaller at the top left corner and gradually increased at the bottom right corner to eliminate the less significant AC components. These quantization matrix entries are chosen as the multiplier of 2 to avoid any division operation.

TABLE II. Q-TABLE FOR Y COMPONENT

8	8	8	8	16	16	32	32
8	8	8	16	16	32	32	32
8	8	16	16	16	32	32	32
8	16	16	16	32	32	32	32
16	16	16	32	32	64	64	32
16	16	32	32	32	64	64	64
32	32	32	32	64	64	64	64
32	64	64	64	64	64	64	64

TABLE III. Q-TABLE FOR E AND F COMPONENT

16	8	8	16	32	32	64	64
16	16	16	16	32	64	64	64
16	16	16	32	32	64	64	64
16	16	16	32	64	64	64	64
16	16	32	64	64	128	128	64
32	32	64	64	64	128	128	128
64	64	64	64	128	128	128	128
64	128	128	128	128	128	128	128

III. RESULTS

In order to show the statistical significance of the proposed method, the quality of the reconstructed images using YEF844 sub-sampling is measured and shown in Table IV. The overall PSNR is calculated by considering all the three color components. From the table, we see that the reconstructed lossy images have peak signal to noise ratio (PSNR) above or equal to 52 dB in all cases. In Fig. 4 several original and their corresponding reconstructed images (using while light imaging, WLI) are shown.

TABLE IV. QUALITY OF DIFFERENT WLI IMAGE FOR YEF844 SUB-SAMPLING

Data type	Number of frames	Average PSNR (dB)			
		Overall	**Y**	**E**	**F**
Still GI Images	100	53.11	52.00	54.43	53.40
Video 1	97	54.03	54.02	54.98	53.27
Video 2	97	54.21	53.82	54.96	53.98
Video 3	97	53.89	53.32	54.75	53.75
Video 4	97	53.47	53.80	53.98	52.77

In Table V, the quality of narrow band imaging (NBI) frames are shown for hundreds of video frames. Here, we see that, the proposed scheme produces high PSNR index for NBI images. In Fig. 5, original and reconstructed NBI images are shown.

TABLE V. QUALITY OF DIFFERENT NBI IMAGE FOR YEF844 SUB-SAMPLING

Data type	Number of frames	Average PSNR (dB)			
		Overall	**Y**	**E**	**F**
Video 1	100	53.20	51.80	54.16	54.09
Video 2	222	53.04	51.34	54.24	54.27

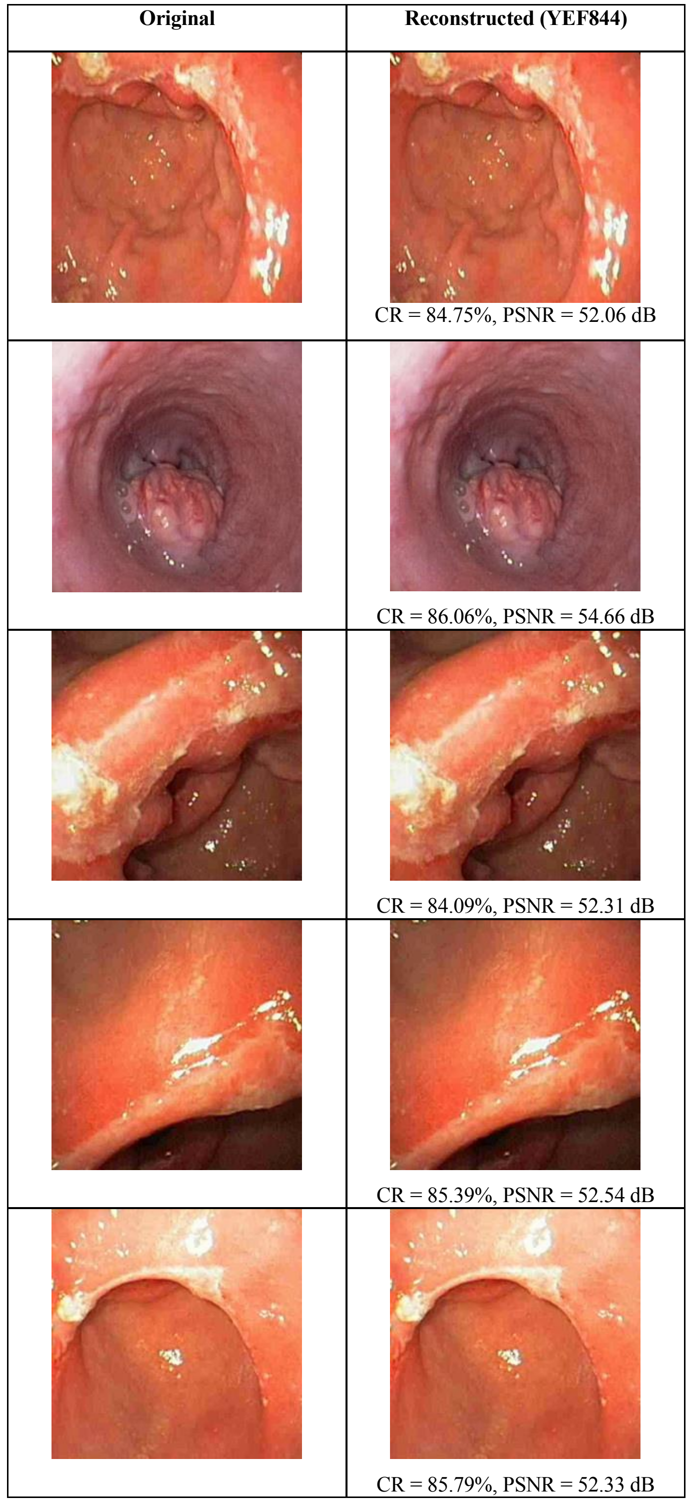

Figure 4. Original and reconstructed (YEF844) WLI endoscopic images

In Table VI, the compression ratio (CR) and image quality in terms of PSNR and Structural SIMilarity (SSIM) index are shown for the proposed algorithm for 12 endoscopy image samples. Here, we find that the average CR is 85.37% and average overall PSNR is 52.90 dB. It also has high average SSIM index of 0.9973.

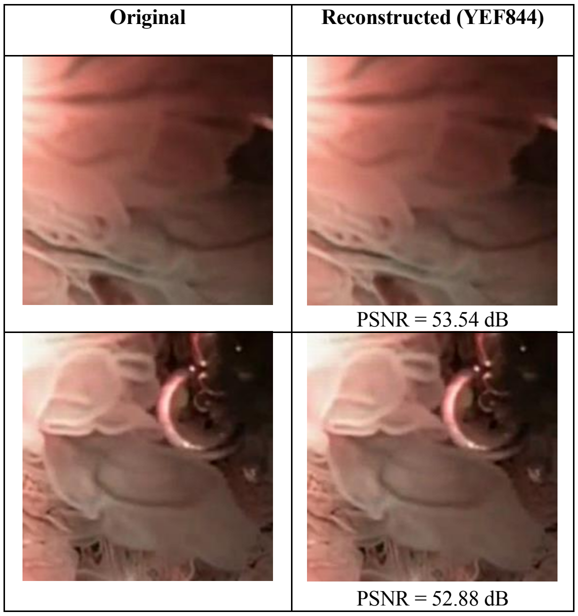

Figure 5. Original and reconstructed (YEF844) NBI endoscopic images

TABLE VI. RESULTS FOR COMPRESSION RATIO AND IMAGE QUALITY

Sample	CR (%)	PSNR overall (dB)	SSIM
1	84.75	52.06	0.9971
2	86.74	53.14	0.9976
3	86.06	54.66	0.9978
4	85.17	53.44	0.9974
5	84.09	52.31	0.9972
6	85.05	52.27	0.9973
7	85.39	52.54	0.9972
8	83.59	52.85	0.9973
9	85.79	52.33	0.9973
10	85.84	53.79	0.9975
11	86.88	53.16	0.9972
12	85.07	52.18	0.9971
Avg.	**85.37**	**52.90**	**0.9973**

In Table VII, the proposed compression algorithm is compared with other related works. From Table VII, we see that the proposed method performs better in CR and PSNR when compared with [6][7][9][10][11][12][13][14] and [15]. The work in [1] and [9] proposes compressors which work on predictive differential coding. Although they have low computational complexity, the CR and PSNR index are lower than the proposed method.

The work in [14] uses iDCT based compressor with sub-sampling as used in the proposed algorithm; however it works on YcgCo color-space. In this work, the YCgCo color-space is replaced by the YEF color-space; and we see that there is a significant improvement in both compression ratio and image quality in the proposed method. Higher CR can reduce RF transmission power; higher image quality is necessary for accurate diagnostics.

IV. CONCLUSION

In this paper, an integer DCT based image compression algorithm is presented that works on an efficient YEF color-space which is specially designed for compressing endoscopic images. A low-cost quantization scheme with chroma sub-sampling is also implemented to achieve higher compression. Simulation results show that the proposed algorithm outperforms many existing techniques in terms of compression ratio and image quality.

TABLE VII. COMPARISON WITH OTHER WORKS

Work	Color space	Avg. CR (%)	Avg. PSNR in dB (overall)
X. Chen [6]	RGB	56.7	46.40
K. Wahid [7]	RGB	87.1	32.90
P. Turcza [8]	YCbCr	91.24	35.70
T. Khan [9]	YUV	80.20	48.20
J. Wu [10]	YUV	50.0	31.00
L. Dung [11]	RGB	82.0	36.20
J. Li [12]	RGB	75.4	47.70
M. Lin [13]	RGB	82.3	40.70
A. Mostafa [14]	YCgCo	84.53	40.64
T. Khan [1]	YEF	80.4	43.70
Proposed	**YEF**	**85.37**	**52.90**

REFERENCES

[1] T. H. Khan and K. Wahid, "Low complexity color-space for capsule endoscopy image compression," *IET Electronics Letters*, vol. 47, no. 22, pp. 1217-1218, 2011.
[2] K. Rao and P. Yip, "Discrete Cosine Transform: Algorithms, Advantages, and Applications", *NY: Academic*, 1990.
[3] J. Liang, T. D. Tran, "Fast Multiplierless Approximations of the DCT with the Lifting Scheme," in *IEEE Transaction on Signal Processing*, vol. 49, 2001.
[4] T. D. Tran, "The BinDCT: Fast Multiplierless Approximation of the DCT," in *IEEE Signal Pro. Lett.*, June 2000.
[5] Standard for Television: VC-1 Compressed Video Bitstream Format and Decoding Process, SMPTE 421M 2006.
[6] X. Chen, X. Zhang, L. Zhang, X. Li, N. Qi, H. Jiang and Z. Wang, "A wireless capsule endoscope system with low power controlling and processing ASIC," *IEEE Transactions on Biomedical Circuits and Systems,* vol. 3, no. 1, pp. 11-22, 2009.
[7] K. Wahid, S. Ko and D. Teng, "Efficient hardware implementation of an image compressor for wireless capsule endoscopy applications," in *Int. Joint Conference on Neural Networks*, 2008.
[8] P. Turcza and M. Duplaga, "Hardware-efficient low-power image processing system for wireless capsule endoscopy," *IEEE Journal of Biomedical and Health Informatics*, vol. 17, pp. 1046-1056, 2013.
[9] T. H. Khan and K. Wahid, "Low power and low complexity compressor for video capsule endoscopy," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 21, no. 10, pp. 1534-1546, 2011.
[10] J. Wu and Y. Li, "Low-complexity video compression for capsule endoscope based on compressed sensing theory," in *Int. Conf. of the IEEE Eng. in Medicine and Biology Society*, 2009.
[11] L. Dung, Y. Wu, H. C. Lai and P. Weng, "A modified H.264 intra-frame video encoder for capsule endoscope," in *IEEE Biomedical Circuits and Systems Conference*, 2008.
[12] J. Li and Y. Deng, "Fast compression algorithms for capsule endoscope images," in *Proc. Int. Congress on Image and Signal Processing*, 2009.
[13] M. Lin and L. Dung, "A subsample-based low-power image compressor for capsule gastrointestinal endoscopy," *EURASIP Journal on Advances in Signal Processing,* vol. 2011, no. 257095, 2011.
[14] A. Mostafa, K. Wahid, and S. B. Ko, "A low-power subsample-based image compression algorithm for capsule endoscopy," In Proc. IEEE International Symposium on Circuits and Systems (ISCAS), pp. 109 - 112, Seoul, Korea, May 2012.
[15] G. Chan, "Toward better chroma subsampling," *SMPTE Motion Imaging J.*, pp. 39–45, May–Jun. 2008.