AN EFFICIENT YUV-BASED IMAGE COMPRESSION ALGORITHM FOR WIRELESS CAPSULE ENDOSCOPY

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ABSTRACT

The paper presents an efficient image compression algorithm for wireless capsule endoscopy application. This algorithm works in YUV colour plane and exploits some special features of human endoscopic images. Based on the nature of endoscopic images, a set of transform-quantization pair is proposed that results in high compression while keeping the reconstruction quality over 45dB. Compared to other transform-based algorithms targeted to capsule endoscopy, the proposed scheme performs strongly with a compression ratio of 90% and high reconstruction PSNR and SSIM (over 48dB and 0.999).

Index Terms— DCT II, Quantization Table, Capsule endoscopy, image compression

1. INTRODUCTION

In order to diagnose the Gastrointestinal (GI) tract of human for diseases, physicians need to examine it. Due to the advancement of technology, it is possible to design swallowable electronic radio-telemetry capsules for the study of GI physiological parameters allowing physicians to wirelessly diagnose the small intestine [1]. The first commercial wireless capsule endoscope system (WCES) was developed by Given Imaging in the year 2000 [7]. In late 2006, Given Imaging disclosed PillCam™ COLON for the screening of colorectal diseases [9]. Some other companies such as Olympus, Pentax, and Siemens entered into the market with similar products [9].

Fig. 1 shows the block diagram of an endoscopic capsule. These capsules should be small, so that the patient can swallow it easily. The noninvasiveness design improves patient's comfort and alleviates pain. For accurate analysis of the disease, the image resolution should be high; but high resolution images require more power to transmit signal. The capsule runs on button batteries that need to supply power for about 8-10 hours [11]. When the power consumption increases due to the high resolution image transmission, the batteries may run out fast and can't take pictures of the whole GI tract. High power batteries require more area, which is not feasible due to the capsule's small size.

Therefore, the quality of image reconstruction, as well as the size of the compressed image are the two key parameters in designing the capsule endoscopy system. In this paper, we present an efficient compression algorithm for the WCES. The algorithm works in the YUV colour space and is tailored taking some special features of the endoscopic images such as, absence of bluish colour, homogeneity of GI skin, etc. Based on our study, a complete compression algorithm with a set of quantization parameters is presented. The simulation results show that the scheme results in high compression (over 90%) with a high quality image reconstruction (over 48dB).

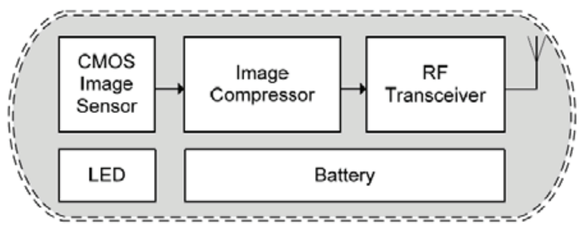

Figure 1: Block diagram of an endoscopic capsule

There have been some works reported on the optimization of compression algorithm targeted to WCES, but all of them work in RGB plane. Here we introduce the analysis of transform coding in the YUV plane that yields much better performance. It should be noted that, most commercial low power image sensors come with an on-chip RGB to YUV converter. The proposed scheme takes the advantage of the built-in converter module to save power.

2. ANALYSIS OF ENDOSCOPIC IMAGES

In this work, twelve endoscopic colour images of different types from [10] have been used. Normally, raw images (i.e., tiff, bmp, etc.) of the GI track are not available as they are transmitted from the capsule in a lossy format. Although not lossless, these images are of very high resolution and high quality. It should be noted that, all other existing works have used these images (from [10]) for their experiments and analysis.

As mentioned earlier, in the proposed algorithm, YUV format is used. There are several reasons for which YUV format provides better performance over RGB format. In

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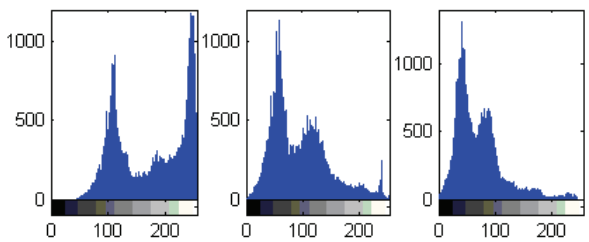
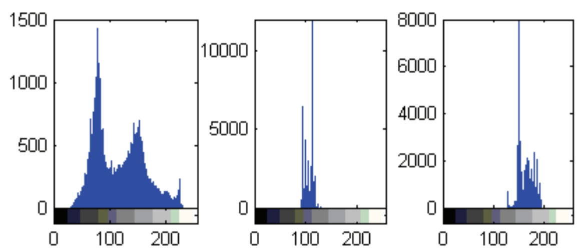
endoscopic images, the red (R) component always dominates the blue (B) and or green (G) components. So, the B components may be heavily sampled to achieve better compression ratio (CR). But in RGB format, the components are inter-related to each other; so heavily sampling one component may deteriorate the overall image quality. This is where the YUV format is advantageous. In YUV format, the Y component contains significant amount of information; hence, it is lightly quantized, but the U and V components contain less information (compared to Y component) and thus may be heavily quantized to achieve a very high CR. Figure 2 shows the information distribution of an endoscopic image in both colour formats.



(a) Histogram of an endoscopic image in RGB format



(b) Histogram of an endoscopic image in YUV format

Figure 2: Histogram of an image in two different formats

3. PROPOSED ALGORITHM

Images are converted from RGB to YUV using the following equation:

$$\begin{aligned} Y &= ((66 \times R + 129 \times G + 25 \times B + 128) / 256) + 16 \\ U &= ((-38 \times R - 74 \times G + 122 \times B + 128) / 256) + 128 \quad (1) \\ V &= ((112 \times R - 94 \times G - 18 \times B + 128) / 256) + 128 \end{aligned}$$

The image is then segmented into 8x8 blocks. The Discrete Cosine Transform (DCT - type II) is applied to each block [8]. The DCT is closely related to the Discrete Fourier Transform. It is a separable linear transformation; that is, the two-dimensional transform is equivalent to a one-dimensional DCT performed along a single dimension followed by a one-dimensional DCT in the other dimension. When any image or image block is transformed using the DCT, the DC components accumulate to the top-left corner of the block. These DC components are critical as they contain the most energy or information entropy compared with the high frequency components which are distributed towards the bottom-right corner of the block. That is why quantization tables contain smaller components at the top-left corner; it is gradually increased towards the bottom-right corner.

In this work, we have analyzed different types of endoscopic images. Based on the properties of Y, U and V components of these images, we present a three different quantization (Q) tables. They are given in Table I, II, and III. The aim here is to maximize the compression ratio while keeping the image reconstruction high which keeps the critical information for accurate diagnosis. It should be noted that, due to the nature of endoscopic images (such as, absence of bluish colour and homogeneity of the GI skin), the U components are heavily quantized. Because of the choices of these parameters in the Q-tables, the high frequency components (i.e., non-critical) are eliminated from the compressed image, which increases the compression ratio (CR) with no unfavorable effects on the reconstructed image.

Table I: Quantization table for the Y component

4	2	2	2	2	4	4	4
2	2	2	2	4	4	4	4
2	2	2	4	4	4	4	8
2	2	4	4	4	4	8	16
2	4	4	4	4	8	16	16
4	4	4	4	8	16	16	32
4	4	4	8	16	16	32	32
4	4	8	16	16	32	32	32

Table II: Quantization table for the U component

8	4	4	8	16	16	32	32
8	8	8	8	16	32	32	32
8	8	8	16	16	32	32	32
8	8	8	16	32	32	32	32
8	8	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: Quantization table for the V component

4	4	4	8	8	8	16	32
4	4	4	8	8	16	32	32
4	4	8	8	16	32	32	32
8	8	8	16	32	32	32	64
8	16	16	32	32	32	64	64
16	16	32	32	32	64	64	64
16	32	32	64	64	64	64	64
16	32	64	64	64	64	64	64

It is also noted that the parameters of these Q-tables are chosen as the multiple of 2, so that the hardware complexity is reduced during implementation. The entire encoding algorithm is shown in Fig. 3. The reverse process is employed for the reconstruction.

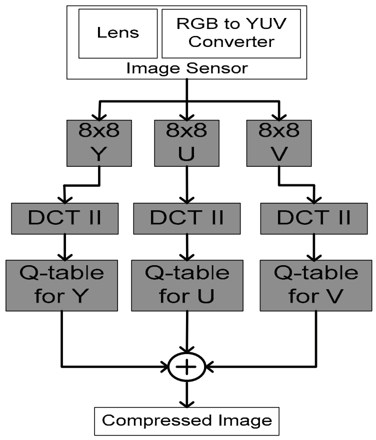


Figure 3: Block diagram of the proposed algorithm

4. PERFORMANCE EVALUATION

In this work, the performance of the proposed method is measured in terms of compression ratios (CR), PSNR, and SSIM [16] as given below:

$$CR = \frac{No. of\ zeros\ in\ the\ compressed\ image}{Size\ of\ the\ original\ image} \times 100\% \qquad (2)$$

$$PSNR = 20\log_{10} \frac{255}{\sqrt{\frac{1}{M \times N}\sum_{n=1}^{N}\sum_{m=1}^{M}(x_{m,n} - x'_{m,n})^2}} \qquad (3)$$

Where, $x_{m,n}$ and $x'_{m,n}$ are original and reconstructed image respectively. M and N are number of row and column respectively.

The results are divided into three categories. First of all, in Table IV, we present the results of the proposed scheme in both RGB and YUV plane. Same Q-tables have been used. No entropy encoding is used in any of the experiments. It can be seen from Table IV that the algorithm performs much better in the YUV format than in RGB. The CR is in the range of 87-91% with PSNR from 47-49dB. This supports the fact that the algorithm, specially tailored to work in YUV plane, works really well in YUV format for endoscopic images.

Secondly, in Table V, we present the results for each colour components to show the effect of the Q-tables. It can be seen that, even after heavy quantization of U and V components, the proposed scheme yields a high PSNR for both of them. The overall performance in terms of PSNR, SSIM, and CR is also reported in Table V.

It has been reported that a minimum PSNR of 35dB in the reconstructed image quality is required for accurate diagnosis [15]. Although, PSNR index is a popular measure of image quality, it may be sometimes deceptive as it does not provide any information about the shape of objects in the reconstructed image. A new evaluation criterion, known as structural similarity index (SSIM) [16], tells about the shape and has become very popular in these days. It is desired that the image processing algorithm to be used in capsule should produce SSIM close to "1". The proposed scheme is able to achieve these two design objectives.

Table IV: Performance comparison of YUV and RGB format using the proposed method

Sample	YUV format			RGB format		
	PSNR (dB)	SSIM	CR (%)	PSNR (dB)	SSIM	CR (%)
1	47.4	0.9909	88.98	39.89	0.9648	82.77
2	47.69	0.9914	90.93	41.49	0.9711	86.16
3	48.43	0.9925	90.17	40.88	0.9578	83.65
4	48.23	0.9919	89.43	40.32	0.9599	82.75
5	47.21	0.9902	88.31	39.58	0.9627	81.53
6	47.27	0.9902	89.31	40.2	0.9672	83.53
7	47.38	0.9905	89.47	40.5	0.9627	83.85
8	47.7	0.9907	87.61	39.29	0.9473	79.92
9	47.56	0.991	89.9	40.99	0.9651	84.48
10	47.81	0.9915	89.95	40.32	0.9615	83.8
11	48.35	0.9913	91.33	42.31	0.9711	86.81
12	47.46	0.9907	89.25	39.75	0.9645	83.09

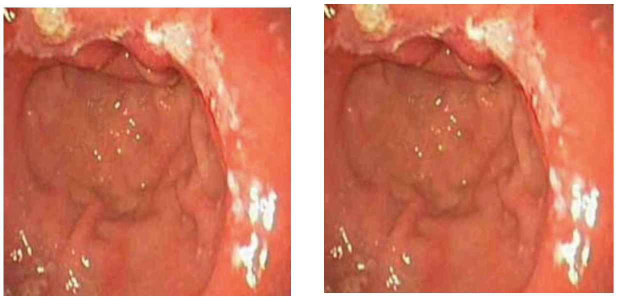
Table V: Performance evaluation in YUV plane

Sample	PSNR (dB)				SSIM	CR (%)
	Y	U	V	Overall		
1	46.82	47.55	47.89	47.4	0.9909	88.98
2	47.61	47.19	48.35	47.69	0.9913	90.93
3	47.24	48.65	49.77	48.43	0.9925	90.17
4	47.03	48.58	49.44	48.23	0.9919	89.43
5	46.46	47.32	47.99	47.21	0.9902	88.3
6	46.98	47.07	47.8	47.27	0.9902	89.31
7	46.97	47.33	47.9	47.38	0.9905	89.47
8	46.36	48.07	49.13	47.7	0.9906	87.61
9	47.4	47.26	48.05	47.56	0.991	89.9
10	47.04	47.84	48.7	47.81	0.9915	89.95
11	47.97	48.09	49.07	48.35	0.9912	91.33
12	46.65	47.9	47.96	47.46	0.9907	89.25

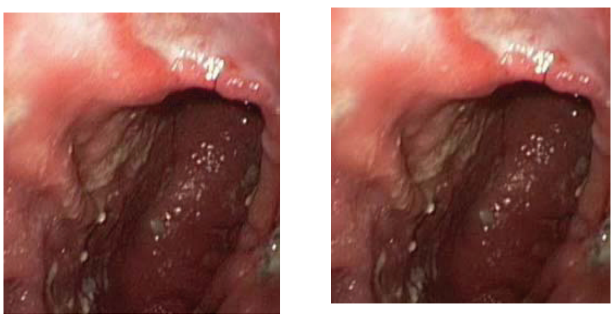
Table VI: Comparison of Performance with other Schemes

	Colour plane	CR (%)	PSNR (dB)
X. Chen *et al.*[2]	RGB	56.70	46.43
K. Wahid *et al.* [3]	RGB	87.13	32.95
P. Turcza *et al.* [4]	RGB	32.00	36.49
M. Lin *et al.* [5]	RGB	79.65	32.51
JPEG-FP [13]	RGB	81.50	31.50
C. Hu *et al.* [12]	RGB	71.98	39.64
J. Wu *et al.* [6]	RGB	50.00	31.02
L. Dung *et al.* [14]	RGB	82.09	36.24
Proposed	**YUV**	**90.17**	**48.43**

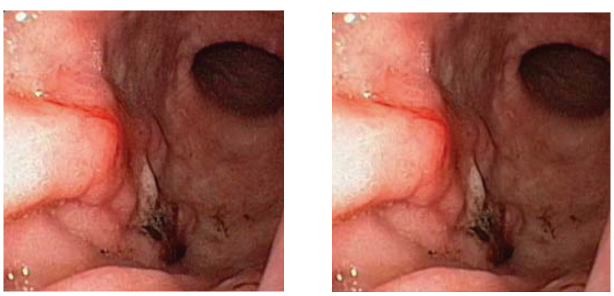
Table VI shows the comparisons the proposed algorithm with other existing schemes targeted to WCES. It can be seen that, the scheme works in YUV plane and outperforms all existing schemes by producing very competitive CR with higher image reconstruction quality. Figure 4 shows some sample original and reconstructed images using the proposed algorithm.



(a) Original (b) Reconstructed CR=88.98%, PSNR=47.4dB



(a) Original (b) Reconstructed CR= 89.43%, PSNR=48.23dB



(a) Original (b) Reconstructed CR= 87.61%, PSNR=47.7dB

Figure 4: Sample original and reconstructed image

5. CONCLUSION

In this paper, a DCT-based image compression scheme is presented for the wireless capsule endoscope system that works on YUV plane. The algorithm is developed around some special properties of endoscopic images. Performance analysis shows that the scheme results in high compression ratio with competitive PSNR and SSIM, and thus outperforms all existing schemes targeted to capsule endoscope application. The algorithm is also very suitable for VLSI implementation.

6. REFERENCES

[1] F. Gong, P. Swain, and T. Mills, "Wireless Endoscopy", Gastrointestinal Endoscopy, 51, no. 6, pp. 725-729, 2000.

[2] X. Chen, et al., "A wireless capsule endoscope system with low power controlling and processing ASIC," *IEEE Transactions on BIOCAS*, vol. 3, no 1, 2009, pp. 11-22.

[3] K. Wahid, et al., "Efficient hardware implementation of an image compressor for wireless capsule endoscopy applications", in *Proc. Int. Joint Conf. on Neural Networks,* 2008, pp. 2761-2765.

[4] P. Turcza and M. Duplaga, "Low-power image compression for wireless capsule endoscopy," in *Proc. IEEE International Workshop on Imaging Systems and Techniques*, 2007, pp. 1 – 4.

[5] M. Lin, et al., "An ultra-low-power image compressor for capsule endoscope," *BioMedical Eng. OnLine*, 5:14, pp. 1-8, 2006.

[6] J. Wu and Y. Li, "Low-complexity video compression for capsule endoscope based on compressed sensing theory," in *Proc. Int. Conference of the IEEE Engineering in Medicine and Biology Society*, 2009, pp. 3727 – 3730.

[7] Pillcam, Given Imaging (2010) [Online], Available: http://www.givenimaging.com/en-us/.

[8] K. Rao and P. Yip, "Discrete Cosine Transform: Algorithms, Advantages, and Applications", NY: Academic, 1990.

[9] A. Moglia, A. Menciassi, and P. Dario, "Recent patents on wireless capsule endoscopy," *Recent Patents on Biomedical Engineering*, vol 1, no 1, 2008, pp. 24-33.

[10] Gastrolab (2010). Available: http://www.gastrolab.net.

[11] D.O. Faigel and D.R. Cave, *Capsule Endoscopy*, Saunders Elsivier, 2008

[12] C. Hu, M. Meng, L. Liu, Y. Pan, and Z. Liu, "Image representation and compression for capsule endoscope robot," in *Proc. IEEE Int. Conf. on Inf. and Auto.,* pp. 506-511, 2009.

[13] C. Cheng, Z. Liu, C. Hu, and M. Meng, "A Novel Wireless Capsule Endoscope With JPEG Compression Engine,"in *Proc. IEEE Int. Conf. on Automation and Logistics*, pp. 553-558, 2010.

[14] L. Dung, Y, Wu, H. C. Lai, and P. Weng, "A modified H.264 intra-frame video encoder for capsule endoscope," in *Proc. IEEE Biomedical Circuits and Systems Conference*, pp. 61 – 64, 2008.

[15] P. Cosman, R. Gray, and R. Olshen, "Evaluating Quality of Compressed Medical Images: SNR, Subjective Rating, and Diagnostic Accuracy", Proc. of the IEEE, vol. 82, no. 6, pp. 919-932, 1994.

[16] Z. Wang, A. C. Bovik, et al., "Image quality assessment: From error visibility to structural similarity," *IEEE Trans. on Image Proc.*, vol 13, no 4, 2004, pp. 600-612.