Article

High efficiency and subsample based image coding algorithm for capsule endoscopy

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Abstract
A simple and efficient image compression algorithm for the capsule endoscopy is given in this paper. The algorithm consist of simplified RGB-YUV colour transform, corner clipping, differential pulse code modulation and Golomb-Rice code. Here, different sub-sampling schemes have been tested on the chroma components. The proposed algorithm do not required any extra memory and has a low computational complexity. The proposed work supports the image sensor which sends the data in zigzag order. The proposed algorithm provides a compression ratio of 83.7% at peak signal noise ratio 45.8. The proposed algorithm provide competition to other works with respect to compression ratio and with JPEG-LS give better performance in terms of compression ratio, memory usage and computational complexity.

Keywords capsule endoscopy; image compression; YUV colour space; subsampling; DPCM; Golomb code.

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1 Introduction

To capture the picture view of gastrointestinal (GI) tract for diagnosing purpose a state of art technique known as capsule endoscopy (CE) has been used. For this, an electronic device of large capsule size is used to capture the image and transmit it wirelessly. This device is swallowed by a person, which capture the images of GI tract using inbuilt camera. The captured images are transmitted to data logger outside the person. The data received in data logger is copied into the personal computer for diagnosing purpose (Khan, 2011a). Due to its comfortable procedure and complete investigation of small bowel, CE preferred over wire endoscopy by the patients (Lin, 2006). Moreover CE has some challenges which need to be overlooked. The main challenges of the CE are limited size and power supply (Ciuti, 2011). The limited bandwidth is due to human body attenuation towards radio wave (Turcza, 2013). The RF antenna consumes 60% of capsule power for data transmission. By reducing the transmission data, power needed for transmission can be saved, which can be used for adding other functions like locomotion, drug delivery, speed controller etc (Fante, 2015). A low complexity, high compression efficient image compression at acceptable image quality is needed (Xie, 2006). A lossy image compression with low complexity is proposed, which consist of simplified

YUV (sYUV) colour space, corner clipping, subsampling, differential pulse coding modulation (DPCM) and Golumb-Rice (G-R) code. To achieve lossy compression algorithm with acceptable image quality different subsampling scheme are proposed. Different parameters of the proposed algorithm are tabled along with standard JPEG-LS. The computational complexity and memory usage of proposed algorithm is also given.

2 Compression Method

The proposed algorithm has five steps: RGB-sYUV colour transform, corner clipping, subsampling, DPCM and G-R code. The block diagram of proposed algorithm is shown in Fig. 1.

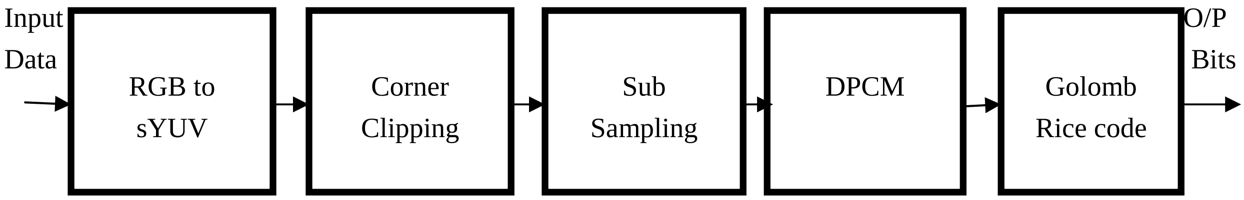


Fig. 1 Block diagram of proposed algorithm.

2.1 sYUV colour space

The commercial image sensor has inbuilt RGB-YUV colour transform. But RGB to YUV conversion implementation in hardware required floating point operation, which consumes extra power and area (Khan, 2012). A simplified YUV (sYUV) color space is derived by considering the special properties of endoscopic images and YUV colour space (Wu, 2009). It is given as

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

$$U = -\frac{R}{8} - \frac{G}{2} + \frac{B}{2} \tag{2}$$

$$V = -\frac{R}{8} + \frac{G}{2} - \frac{B}{2} \tag{3}$$

From the equations (1), (2) and (3) observed that they need few addition and shift operations and their hardware implementation is simple due to low complexity. Fig. 2 represents the intensity distribution of RGB, where observed that intensity distribution of RGB is wide compared to sYUV components (Fig. 3). Fig. 3 represents the intensity distribution of sYUV component, in which it is observed that U and V components has less information, which lead to high compression of data.

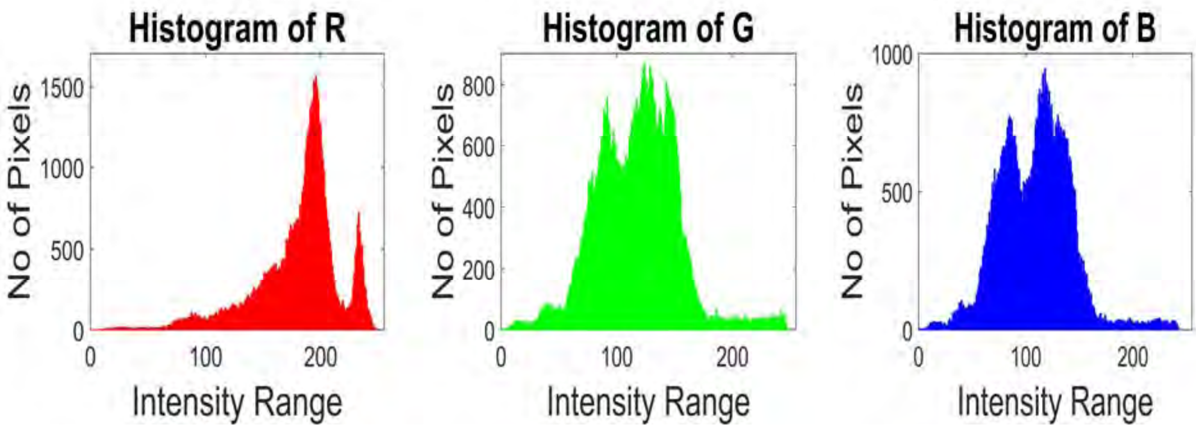


Fig. 2 Histogram of R, G and B components.

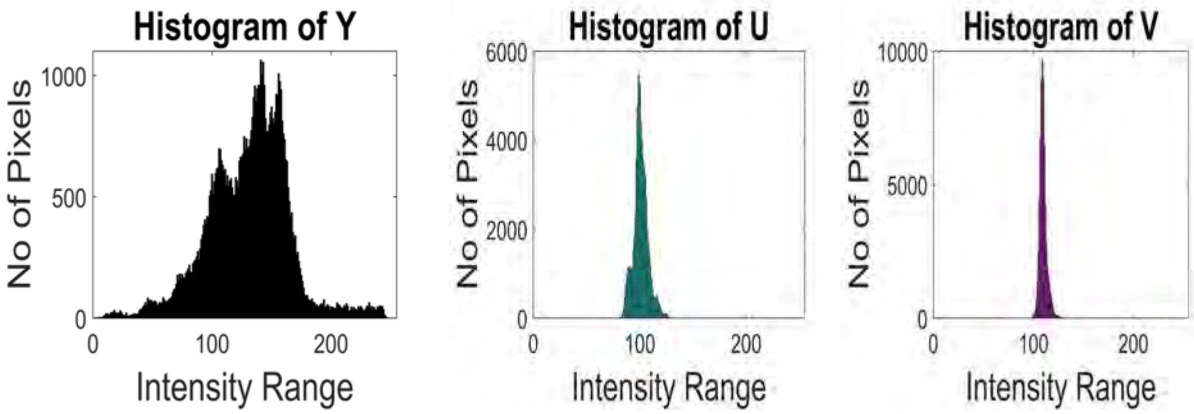
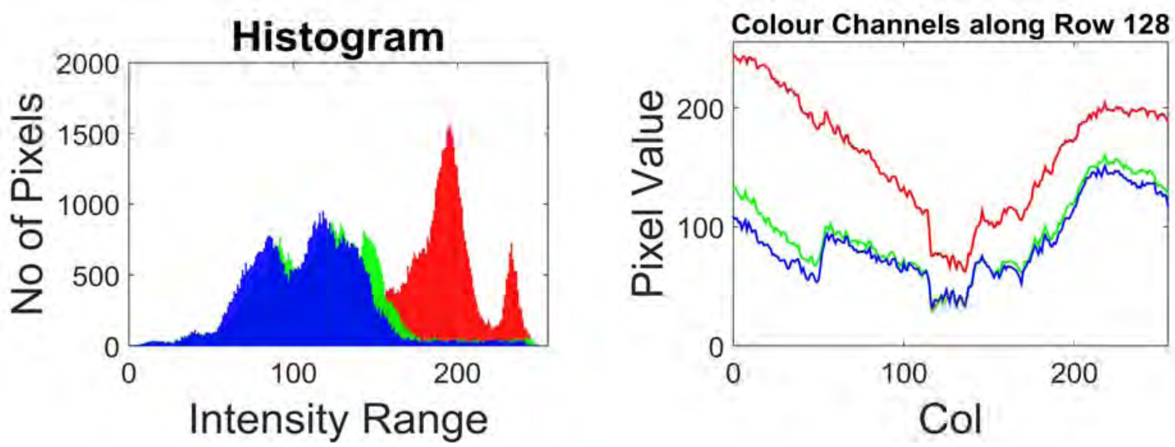


Fig. 3 Histogram of simplified Y, U and V components.

The sYUV is designed based on the special characteristic of endoscopic image and analyzing GI tract images (Khan, 2011b). From the experiments, it is observed that most of GI tract images are red in colour i.e. red dominate more compared to blue and green as seen in Fig. 4 (a). From Fig. 4 (b) can be seen that green and blue components are of same pattern.



a b

Fig. 4 (a) Histogram of RGB colour image; (**b)** Colour channels along Row 128 of RGB colour image.

In the traditional YUV colour space, U and V components represents the blue and red chroma components. However, in the endoscopic images, green and blue components are of same pattern and contain less information. So the V components i.e. red chroma is replaced by green chroma component in the proposed sYUV colour space.

In Table 1 average standard deviation and average entropy of RGB, YUV and sYUV is shown, where it is observed that proposed sYUV has competitive average standard deviation and entropy value compared to others, which can help in obtaining more compression. The sYUV is another representation of RGB and can be reversible using equations given below.

$$R = -4U - 4V \tag{4}$$

$$G = \frac{4}{3}Y + U + \frac{5}{3}V \tag{5}$$

$$B = \frac{4}{3}Y + 2U + \frac{2}{3}V \tag{6}$$

Table 1 Average standard deviation and entropy of colour spaces

Colour space	Components	Avg.Std	Avg.entropy
RGB	R	42.7	7.1
	G	32.3	6.4
	B	29.8	6.2
YUV	Y	29.6	6.4
	U	3.9	3.8
	V	8.4	4.8
sYUV	Y	33.6	6.5
	U	7.2	4.6
	V	4.4	3.9

2.2 Subsampling

To obtain an optimal subsampling scheme for endoscopic images, analyzing of its unique properties has been done. For analyzing purpose two different type of images are taken, one is the endoscopic image and another is the standard image. It is identified that variation in Y component of both images are similar, but variation in U and V component of standard image is wide compared to endoscopic image. The narrow variation in chroma component of endoscopic image is due to colour homogeneity of GI tract images. The U and V component of endoscopic images can be subsampled more as they do not hold important information. The heavily subsampling of chroma components tends to achieve more compression efficiency without any effect on image quality (Khan, 2011c). Moreover, these images are diagnosed visually and eye is more sensitive to brightness than colour. The subsampling of chroma component leads to distortion, which is not observed by eye due to its less sensitivity to colour (Cosman, 1994). From Fig. 3, it is observed that variation in U component is wide compared to V component. This is due to absence of blue colour in endoscopic images. This observation can lead to selection of subsampling scheme for endoscopic image. Since distortion in Y component can be observed by eye, subsampling of it can lead to loss in image quality.

2.3 Differential pulse code modulation

In the endoscopic images the homogeneity between pixels is more due to rare sharp edge in it. The difference between consecutive pixel values can be small. The difference value (dE) obtained from difference between pixel value and adjacent pixel value is given as

$$dE = x - x_d \quad (7)$$

where x is the present pixel value, x_d is the adjacent pixel value and E represents the Y, U and V components. Fig. 5 show the change in pixels for RGB of endoscopic images, where it is observed that the pixels variation is more. Fig. 6 show the change in pixels for sYUV of endoscopic images, where it is observed that in U and V component pixels variation is less due to less information in chroma component. The best choice is DPCM, where current pixel value is subtracted with the previous pixel value to provide difference value. Moreover, DPCM is lossless encoding scheme with less computational complexity. It will save the power and area consumption.

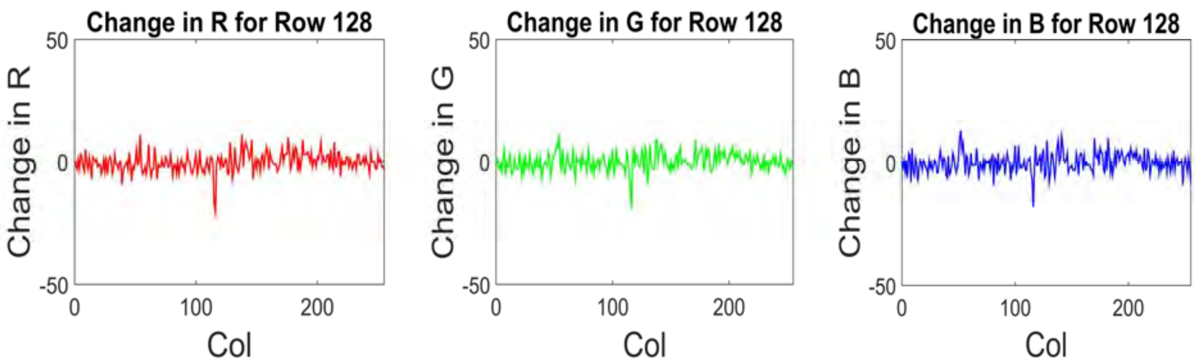


Fig. 5 Difference values (dE) of R, G and B components.

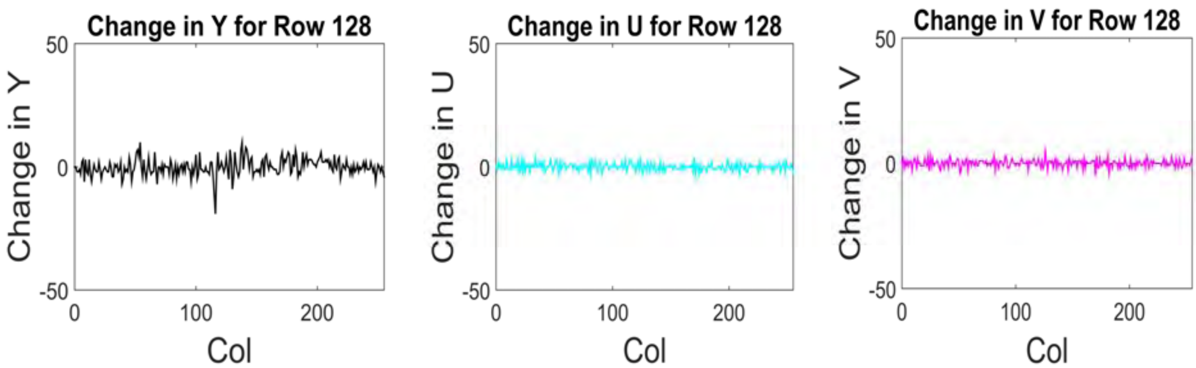


Fig. 6 Difference values (dE) of simplified Y, U and V components.

2.4 Golomb-Rice code

A suitable encoding scheme has been selected, which is efficient in coding the difference value (dE) and less error prone. The objective is to provide less bits to support limited bandwidth of CE application. By analyzing the dE values of sYUV component, it is observed that occurrence of difference value in U and V component is narrow. It can be noticed from Fig. 7, where intensity distribution of dE for sYUV component is shown. Here Golomb-Rice (G-R) code is chosen as it provides good result for less values. G-R code is simple and its hardware implementation is easy. The G-R code works with positive integers only and difference value obtained can be of any value. So, negative values are converted to positive using equation (8). The G-R code used follow the procedure given in (Khan, 2011a)

$$m\_dE = \begin{pmatrix} 2\,|\,dE\,| - 1, when\, dE < 0 \\ 2dE, when\, dE \geq 0 \end{pmatrix} \tag{8}$$

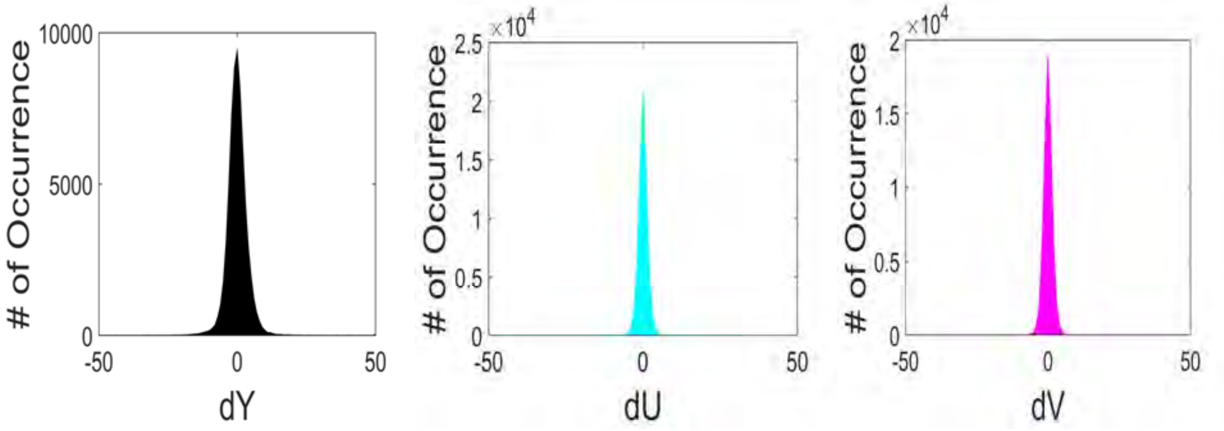


Fig. 7 Histogram for difference values (dE) of simplified Y, U and V components

2.5 Corner clipping

Image sensor used in CE contains circular shape lens due to which corners of image contains non informative pixel. To use this for better compression efficiency, pixels at corners are replaced by black pixel using the algorithm given in (Khan, 2011a).

3 Performance Analyzing Parameters

The proposed compression algorithm is implemented using PC software and the results are observed. The performance of the image compression algorithm is measured using compression rate and reconstruction rate. To measure the compression rate and reconstruction rate of image, compression ratio (CR) and peak signal to noise ratio (PSNR) is used (Khan, 2011b). The CR is calculated using equation (9) and PSNR using equation (10)

$$CR = \left(1 - \frac{Total\ Bits\ After\ Compression}{Total\ Bits\ Before\ Compression}\right) \times 100 \tag{9}$$

$$PSNR = 20\log_{10} \times \frac{255}{\sqrt{(1/A \times B \times 3)\sum_{c=1}^{3}\sum_{b=1}^{B}\sum_{a=1}^{A}\left(x_{a,b,c} - x'_{a,b,c}\right)^2}} \tag{10}$$

Where A and B are the height and width of image and c is the colour components.

4 Results and Discussion

In this paper, 30 sample images of GI tract is considered for the performance analyzing purpose. These images are picture view of all GI tract parts. Different subsampling scheme has been applied on this sample image and their compression ratio and PSNR are calculated. Since all the results cannot be displayed, average of sample for each scheme is taken. In Table 2 compression ratio and PSNR of different subsampling schemes are shown, where it is observed that YUV 8:8:8 scheme provide less CR 69.1% with 100% PSNR. The YUV 16:1:1 scheme provide high CR 86.8% with PSNR 42.3.

Table 2 Comparison of different subsampling scheme.

Sub-Sampling Scheme	CR%	PSNR
YUV888	69.1	∞
YUV422	77.0	52.9
YUV412	80.3	50.4
YUV822	81.5	47.2
YUV814	82.8	48.0
YUV812	83.7	45.8
YUV811	84.1	43.7
YUV16.1.2	86.8	42.3

In Table 3 comparison between the proposed algorithm and JPEG-LS algorithm is done, where it is observed that proposed scheme outperforms JPEG-LS with respect to compression ratio, memory usage and computational complexity.

Table 3 Comparison between Standard JPEG-LS and proposed algorithm.

	JPEG-LS	Proposed
Colour Plane	RGB	YUV
Prediction Modes	Seven	One
Buffer Memory	1.9Kb	0
K-Parameter	Dynamic	Fixed
Run Mode	Yes	No
CR%	57.9%	69.1%

In Table 4 comparison between proposed scheme and other works is done. It can be identified from the comparison table that proposed work provide good compression ratio with high PSNR. The proposed work has low computational complexity (O(n)) and do not need any extra buffer memory. The proposed work outperforms the other works (Wu, 2009; Lin, 2006) with respect to compression ratio and PSNR. The proposed work gives competitive compression ratio, in comparison to technique (Wahid, 2008; Turcza, 2013). However DCT based compression algorithm has high computational complexity (O(nlogn)) and need extra memory to store image. Work presented in (Khan, 2011a, 2011c, 2012; Fante, 2015) are DPCM based which use traditional YUV color plane. The hardware implementation of YUV is difficult due to floating points.

Table 4 Comparison between proposed algorithm with other algorithms.

	CR%	**PSNR**	Memory	**Complexity**
Lin 2006	79.6	32.5	YES	O(nlogn)
Wahid 2008	87.1	32.9	YES	O(nlogn)
Wu 2009	50.0	30.0	YES	$O(n^3)$
Khan 2011a	73.2	∞	NO	O(n)
Khan 2011c	80.4	45.5	NO	O(n)
Khan 2012	81.5	43.2	NO	O(n)
Turcza 2013	91.2	35.7	YES	O(nlogn)
Fante 2015	82.1	46.6	NO	O(n)
Proposed	83.7	45.8	NO	O(n)

5 Conclusion

A low complexity image compression algorithm for capsule endoscopy is given in this paper. The proposed work consists of sYUV colour space, corner clipping, subsampling, DPCM and G-R code. The subsampling scheme is used for obtaining better compression efficiency. The scheme is obtained by analyzing the special properties of endoscopic image. The proposed algorithm is simple and uses less memory. It provides competitive compression ratio compared to other works and standard JPEG-LS algorithm.

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