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Hybrid Block Coding of Medical Images Using the Characteristics of Human Visual System

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=Abstract=

The demand of image compression is increasing now for the integration of medical images into the hospital information system. Even though the quantitative distortion can be measured from the difference between original and reconstructed images, it doesn't include the nonlinear characteristics of human visual system. In this study, we have evaluated the nonlinear characteristics of human visual system and applied them to the compression of medical images. The distortion measures which reflect the characteristics of human visual system has been considered. This image compression procedure consists of coding scheme using JND (Just Noticeable Difference) curve, polynomial approximation and BTC (Block Truncation Coding).

Results show that this method can be applied to CT images, scanned film images and other kinds of medical images with the compression ratio of 5-10:1 without any noticeable distortion.

Key words : Image compression, Distortion measure, Human visual system, JND, BTC

Introduction

In these days, medical images are generated and converted to digital form and widely accepted for the clinical use. For the efficient use of these medical images, PACS (Picture Archiving Communication System) is studied and tried for the clinical applications. In this case image compression is a significant factor for efficient storage and transmission of medical images.

Image compression is to reduce the data size without any loss or with minimum loss of image contents. Like any other digital images, medical images also have innate redundancy among nearby pixels. This redundancy is not necessary for image representation, and we can eliminate this by some mathematical techniques. And, additional compression can be applied to these redundancy-free images by means of variable length coding or optimal quantizer[1, 2].

In mathematical sense, many methods have been developed to generate optimal codes of images[2]. But, there are some difficulties in applying these methods to medical images directly. Because the medical images are being used in the diagnosis of diseases, the meaning of distortion in medical images is quite different from that in other kinds of images.

Also, the bit rate should be low as possible. So, in medical image compression, the methods which can compress 10 to 1 or more, have not been adopted because of their distortion and complexities. Instead of those high compression ratio methods, the simple, stable and lossless compression algorithms like DPCM, Huffman coding, and RLC have been preferred[3].

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In this paper, we have focused on the problem of using mean square error as distortion measure in the compression of medical images. And we have proposed the distortion measure which is based on the characteristics of HVS (Human Visual System). And, we have developed the hybrid coding scheme based on these characteristics of HVS.

The characteristics of HVS used in image compression

Since the times of Shannon, MSE has been most widely used as a distortion measure in data compression. MSE is the power of differences between two signals. If we define 'Information' as 'identified bit stream', it would be reasonable to use MSE as a distortion measure between two signals.

But, the final receptor of image is human visual system and human get information through the illumination of images. From this point of view, it is more appropriate to regard the 'information of image' as 'identified illumination distribution' than as 'identified bit stream'.

Several studies to compensate MSE measure have been performed using nonlinear distortion measures[4, 5, 6]. From psychophysiological experiments, we can derive the characteristics of human visual system, and apply them in image compression procedure. Image compression based on the characteristics of HVS will be more acceptable than other methods using linear quantitative measure within same bit rate.

The mechanism of human visual perception has not been revealed fully yet, but there are some characteristics that can be useful in image compression.

Firstly, we can use the Just Noticeable Difference (JND) of illumination around variable background illuminations. In the discrimination of brightness difference, HVS is dependent on its background brightness. The background brightness is set to Bg, and the object brightness is set to Og, which is equal to Bg initially. At the beginning, because Og is equal to Bg, one cannot notice the object. Then, increase Og to Og_N, until one can just notice the object. The brightness difference between Bg and Og_N is said to 'Just Noticeable Difference in Bg ($J(Bg)=|Bg-Og_N|$)'. We can get the JND curve by measuring the Og_N values with the variation of Bg.

Secondly, HVS is affected by 'spatial masking effect'. If there is great difference of pixel values, it forms edge. It is known that the degradation visibility near edges is decreased by the spatial masking effect[7]. Because most of the informations are in the edges of image, the position and values of edges should be well preserved. But, the error nearby edge is less visible than the error in plain region. Several trials using the characteristics of HVS have been performed. Even though the quantitative understandings of human visual system is not sufficient, combining of these characteristics to image compression can be more efficient than mere mathematical coding method.

Block coding scheme using the characteristics of HVS

We have divided the original image into small blocks, and applied the hybrid coding method based on the statistics of the blocks. Fig. 1 shows the procedure for image coding.

We have classified the blocks into four groups; the perceptually uniform blocks, polynomially approximate blocks, edge containing blocks, and remaining complex blocks. To the first three groups, proper compression method have been applied. And, the remaining blocks have been assigned 'complex block'. Blocks of this group are difficult to compress efficiently and stored in their raw data form. Classification criteria and compression procedures for each group of blocks are as follows.

1. Classification of Perceptually Uniform Blocks

The minimum distinguishable difference of illumination is varying with background illuminations. It is also related to the nonlinearity of the monitor, which is known as gamma effect. Fig. 2 shows the results of JND experiment for the image display monitor, as described in section II. The experiment was performed in the dark. The subject should reply whether the square object (which is brighter than the background by Og-Bg) is visible or not. This results shows HVS is not sensitive in dark region, and becomes more sensitive in region of mid range, and less sensitive in bright re-

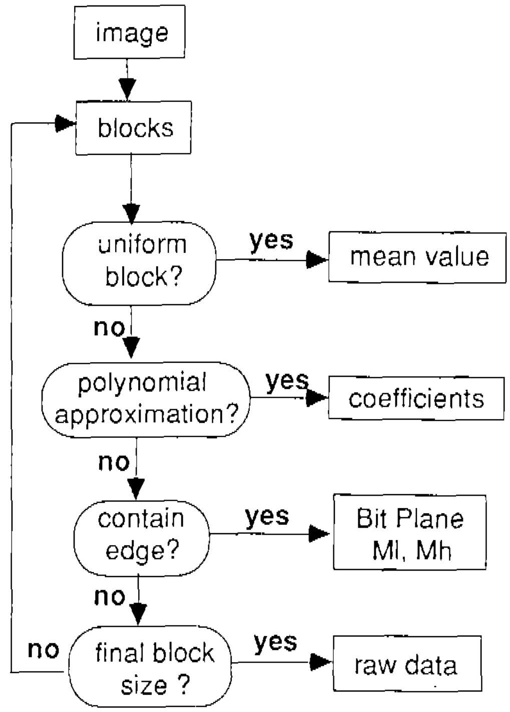


Fig. 1. Block diagram for the hybrid block coding

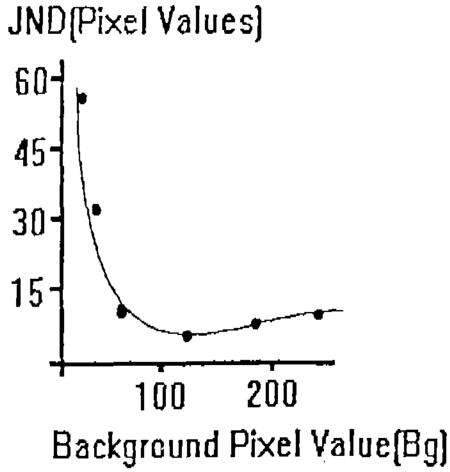


Fig. 2. The result of JND experiment

gion.

If a block has uniform pixel values, the block can be represented by its mean value. In the first step, we have determined the block is uniform or not. The more blocks are classified to this group, the lower bit rate the image can be compressed to. But there are not so many perceptually uniform blocks. If any block has so little fluctuation that we percept the block as uniform, this block is regarded as uniform block. The homogeneity of the block should be checked and then compared with the specified threshold value. In our method, we have used the JND curve value as the threshold for the classification of blocks. Even though the fluctuation in the dark region is greater than the region of mid range, the fluctuation would not be noticed by HVS because the properties of JND curve. So, we could classify more blocks to the 'perceptually uniform blocks' by using JND values as the thresholds than using a single specified threshold value. The steps for classification of perceptually uniform blocks are below.

(1) The mean value(M) of the block is calculated and considered as background illumination of the block.

(2) The maximum difference(D) between mean value and the pixel values is calculated and considered as inhomogeniety.

(3) If D is smaller than JND(M), the block is classified as the 'perceptually uniform blocks'.

(4) If not, go to the next stage for the classification to the 'polynomially approximate blocks'.

2. Classification of Polynomially Approximate Blocks

The image can be represented as the 2-D function of $z=f(x, y)$, where z is gray level. We approximated N×N pixel values of a block to a polynomial function as in Eq. (1), and the coefficients a0-a5 has been stored instead of pixel values of block for this group of blocks.

$$f^*(x, y)=Z^*=a_0+a_1x+a_2y+a_3xy+a_4x^2+a_5y^2 \qquad (1)$$

To estimate each coefficients, the least square error method has been used. After estimate the coefficients, we have calculated the distortion error between original block and the reconstructed block using coefficients. If the error was smaller than the specified threshold, the block has been classified to the polynomially approximate block. Most of the slowly varying blocks belong to this group. But the blocks containing sharp edges can not be approximated by this polynomial function. To such blocks, the next coding procedure has been applied.

3. Block Truncation Coding

The blocks containing sharp edges are neither uniform nor polynomially approximate. But we can use spatial masking effect that the noise nearby edge is less visible than at the uniform region. So we should adopt the coding method which preserves the edge location but neglects some degradation near the edge for efficient compression. The Block Truncation Coding has been applied suitably for this purpose by Delp and Mitchel[7]. This method is efficient for blocks which contain sharp edge, especially whose histogram has the bimodal form.

In this stage, many of simple blocks already have been processed by first and second coding procedures(1, 2). The remaining blocks have sharp edge like characters, or man-made objects. Classification and coding procedure for this group of blocks are as follows.

(1) calculate mean value of the block (E(x))
(2) compare pixel values of the block with the mean value
(3) make a bitmap for the block which sets '1' for over threshold valued pixel and '0' for under threshold valued pixel.
(4) calculate the means and variances of over threshold valued pixels (Mh) and under threshold valued pixels(Ml).
(5) check these variances for the classification to BTC group
(6) for the classified blocks to this group, store bitmap, block mean value and standard deviation.

$$Mh=\frac{1}{q}\sum_{i=1}^{q}x_i \qquad when\ x_i>\bar{x} \qquad (2)$$

$$Ml=\frac{1}{N^2-q}\sum_{i=1}^{N^2-q}x_i \qquad when\ x_i\leq\bar{x} \qquad (3)$$

where q is the number of pixels which are greater than E (x) of the block.

4. Splitting and the Remaining Blocks

In this coding procedure, all the blocks have checked for the classification to each group, and have compressed by the different methods in each step. The remaining blocks can be regarded difficult to compress by the above coding procedures. For these blocks, we divided a block into four sub-blocks. Although the N×N block could not belong to first three groups above, some of N/2×N/2 sub-blocks may belong to one of them. So, we have applied the above three coding procedures again to these sub-block.

For the finally remaining few sub-blocks of N/2×N/2, it was difficult to apply efficient compression method. And, because these blocks can be thought to have some diagnostic information, these blocks have been stored in their raw data form without any loss of information.

Results

The original images on film were scanned with 1024×768×8 bit resolution using laser film scanner(Lumiscan 100), and displayed on display monitor(SAMSUNG SyncMsater3). We have applied above multi-stage hybrid block coding algorithm to these images. The sizes of block and sub-block are 16×16 and 8×8 respectively. In the proposed algorithm, the thresholds used in each steps determine the error in the result and the bit rate. We have examined results with varying the threshold values. Table 1 and 2 show results in each of four threshold stages for chest and CT images. The PSNR is Peak Signal to Noise Ratio and the percentage is the fraction of blocks belonging to each group. The Fig. 3 and 4 show the results of the Table 1 and 2.

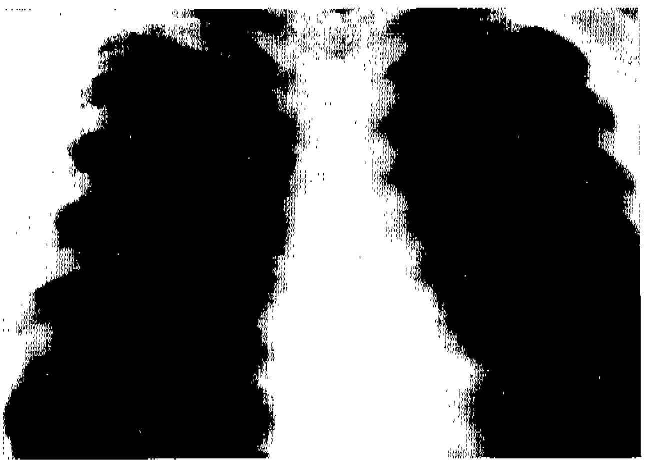
Discussion and Conclusion

According to Table 1 and 2, many blocks can be classified to 'perceptually uniform block' and 'polynomially approximate block'. The compression ratio of 8.60 is good without visible degradation. In chest images, most of structure is smooth in nature, and the polynomial approximation can be applied effectively. But for CT images and MR Images, which contains man-made patterns(like characters and lines) the third group of BTC has been more effectively used than coding procedures. As Increasing the threshold values, the block artifact may be seen as stage 3.

Even though MSE is optimal distortion measure in mathematical sense, it does not include the nonlinear characteristics of human visual system. So the distortion measure

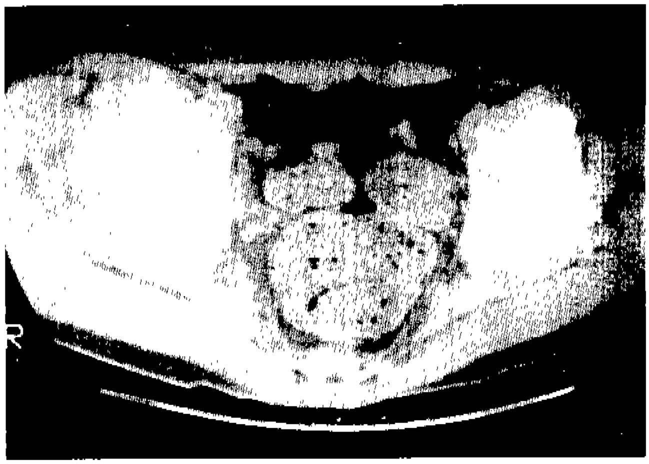
a) The original image(1024×768×8 bits)

b) The reconstructed image of stage 1(8.6:1, PSNR=48.27)

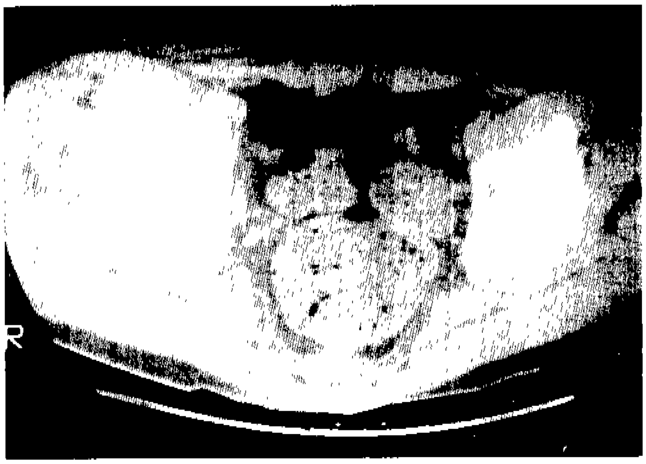


c) The reconstructed image of stage 3(21.05:1, PSNR=45.16)

Fig. 3. The results for the scanned chest X-ray image



a) The original image(1024×768×8 bits)



b) The reconstructed image of stage 1(5.19:1, PSNR=44.96)

c) The reconstructed image of stage 3(11.11:1, PSNR=42.14)

Fig. 4. The results for the CT image

Table 1. The compression results of chest X-ray image

	Stage 1	Stage 2	Stage 3	Stage 4
Uniform(%)	28.75	54.22	78.26	87.87
Approx.(%)	69.75	44.90	20.21	11.81
BTC(%)	0.40	0.42	0.24	0.15
ETC(%)	0.21	0.13	0.09	0.06
PSNR(dB)	48.27	47.24	45.16	44.03
Comp.Ratio	8.60	12.31	21.05	27.59

Table 2. The compression results of CT image

	Stage 1	Stage 2	Stage 3	Stage 4
Uniform(%)	12.98	30.10	64.90	78.33
Approx.(%)	47.17	39.04	23.75	15.60
BTC(%)	34.09	26.88	9.38	4.31
ETC(%)	5.74	3.98	2.40	1.69
PSNR(dB)	44.96	44.06	42.14	41.08
Comp.Ratio	5.19	6.67	11.11	15.38

have been improved by including the characteristics of human visual system. By combining characteristics of human visual system we can compress the medical images more effectively.

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