Medical Image Compression Based on High Fidelity SPIHT

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Abstract

Due to the bandwidth and storage limitations, medical image must be compressed before transmission. The set partitioning in hierarchical trees (SPIHT) algorithm is an efficient method for lossy and lossless coding of medical image. This paper presents some modifications on the SPIHT algorithm. It is based on the idea of insignificant correlation of wavelet coefficient among the medium and high frequency subbands respectively. In this scheme, insignificant wavelet coefficients that correspond to the same spatial location in the medium subbands can be used to reduce the redundancy by a combined function that modified SPIHT proposes. In the high frequency subbands, the modified SPIHT proposes dictator to reduce the interband redundancy. Experimental results show that the proposed technique improves the quality of the reconstructed medical image in both PSNR and perceptual result when compare to JPEG2000 and original SPIHT at the same bit rate.

Keywords: SPIHT, JPEG2000

1. Introduction

The medical images include computer tomography (CT), magnetic resonance imaging (MRI), ultrasonography (US), and X-rays. The modalities provide flexible means for viewing anatomical cross sections and physiological states, and may reduce patient radiation doses and examination trauma. However, the medical images have large storage requirements. Because of the storage capacity limitation, medical image compression techniques are needed to reducing the storage requirements. In medical applications, large volumes of digitized images are presented, so image compression is indispensable. In recent years, there are some standards built in American Industrial, like: ACR/NEMA[1], and DICOM[2], there are all applied in lossy compression method. The SPIHT [3] is the encoded algorithm for the medical images, because of the SPIHT algorithm was an efficient method for lossy and lossless coding of still images.

Section 2 reviews the original SPIHT algorithm of Ref. [3]. Section 3 presents the modification and algorithm in detail. Simulation results and comparison with JPEG2000 [4] and original SPIHT are presented in section 4 for several kinds of medical images. Section 5 presents the conclusion.

2. Original SPIHT algorithm

The SPIHT algorithm, introduced by A. Said and W.A. Pearlman, adopts a hierarchical quadtree [5][6] data structure on wavelet-based [7][8] image. Figure 1 indicates the parent-child relationship through the subbands (quadtree). The original SPIHT is briefly described as follows. The wavelet coefficient are encoded and transmitted in multiple passes in the SPIHT algorithm.

1) Thresholding:

In each pass, only the wavelet coefficients that exceed threshold are encoded. The threshold *T(u)* is computed according to the expression

$$T(u)=2^{P-u} \quad (1)$$

,where u=0, 1, 2, 3…, P denotes the pass number.

$$\text{And } P=\lfloor \log_2 \max(c(i,j)) \rfloor \quad (2)$$

,where *c(i, j)* is the coefficient at position *(i, j)* in the image.It just sends the max value to the decoder, and the thresholds can be calculated by (1) and (2).

2) Sorting pass:

When $u=n$, n is integer. The pixel that satisfying $T(n) \leqq |c(i, j)| < 2T(n)$ is identified as significant. $c(i, j)$ is coefficient value. The pixel's position and sign bit must be encoded.

3) Refinement pass:

The pixels that satisfying $|c(i, j)| \geqq 2T(n)$ are refined by encoding the *n*th most significant bit (those that had their coordinates transmitted in previous sorting passing).

4) Increment *u* by one, and go to step 2).

3. Propose method

We propose a method to modify the original SPIHT algorithm to be suitable for medical images. The original SPIHT algorithm was an efficient method for lossy and lossless coding of natural images. We modify the original SPIHT algorithm, according to the characteristic that the wavelet coefficients of medical images are more centered on the low frequency than those of natural images. And medical images have less edge than natural image. In addition, the quality of medical compressed image must reach an acceptable level in terms of the diagnosis.

Table 1. Correlation in LH_3, HL_3, and HH_3

Image	Same condition	Different condition
Xhead1	97.5%	2.5%
Angio2	95.0%	5.0%
Ctbone2	93.4%	6.6%
Ercp2	95.6%	4.4%
Utheart3	80.4%	19.6%

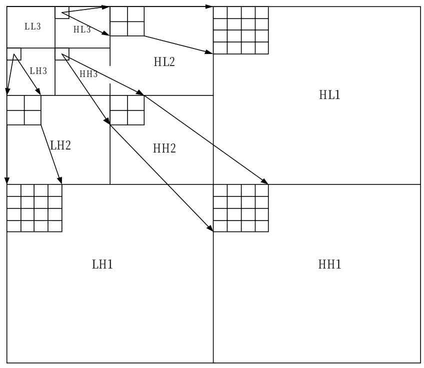


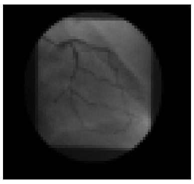
Figure 1: Parent-child relationship

The original SPIHT algorithm ignores the correlation within the same level subbands. For the insignificant coefficients in the high frequency, original SPIHT algorithm saves the space using quadtree concept. In Figure 1, the nodes (coordinates in LL_3) have no descendent trees; the nodes (coordinates in LH_3, HL_3, and HH_3) are the roots of the quadtree, and the remainder nodes (coordinates in other subbands) are tree nodes. There is large correlation between LH_3, HL_3 and HH_3. Table 1 shows the correlation of the same coordinates in LH_3, HL_3, and HH_3 in several kinds of medical images (Figure 2). Same condition means that the coefficients at equal coordinate in LH3, HL3, and HH3 have at least an important value. Different condition means that the coefficients at equal coordinate in LH3, HL3, and HH3 have not important values. In xhead1 test image, percentage of the insignificant coefficients at the same coordinate in LH_3, HL_3, and HH_3 is 97.5%. This statistics shows that the percentage of the significant coefficients in subbands (not include LL_3) is rare. These coefficients are essential to reconstruct image edges. Large redundancies were hidden in presentation of these coefficients. In utheart3 test image, percentage of the different condition slanted to higher than other test images. The main reason is that the utheart3 sample context is more complex than the others. Table 2 shows that the correlation of the same coordinate in

LH_1, HL_1, HH_1, LH_2, HL_2, and HH_2 in all recursions in several kinds of images (Figure 2). Same condition means that the treenode's coefficients are at least important on the quadtrees that's roots are at equal coordinate in LH3, HL3, and HH3. Different condition means that the treenode's coefficients are not important on the quadtrees that's roots are at equal coordinate in LH3, HL3, and HH3. That is, the medical image that encoded by the original SPIHT algorithm has many redundancies.

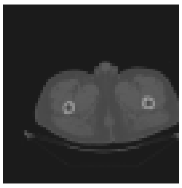
Table 2. Correlation in LH_1, HL_1, HH_1, LH_2, HL_2, and HH_2

Image	Same condition	Different condition
Xhead1	99.7%	0.3%
Angio2	97.3%	2.7%
Ctbone2	97.6%	2.4%
Ercp2	97.4%	2.6%
Utheart3	80.3%	19.7%

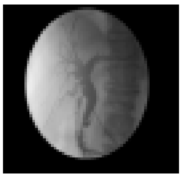


Angio2 (a)

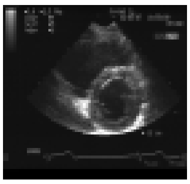
Xhead1 (b)



Ctbone2 (c)



Ercp2 (d)



Utheart3 (e)

Figure 2: Test image.

This work exploits the same level subband relation that is ignored by the original SPIHT algorithm to decrease redundancy. After wavelet transform, the energy is centered on the wavelet coefficients on low-low band. According to this characteristic, the modified SPIHT algorithm divides wavelet-transformed image into three partitions. The partitions include that α is a partition of the low frequency coefficients, β is a partition of the middle frequency coefficients, and γ is the partition of the high frequency coefficients. *C* represents that wavelet coefficients are significant or not, and *(x, y)* is the coordinate of the image. If the wavelet coefficient *c(x, y)* is larger than threshold value T, then *C(x, y)* set 1. If the wavelet coefficient *c(x, y)* is smaller than threshold value T, then *C(x, y)* set 0.

$$\alpha = \{C(x, y) \mid (x, y) \text{ in } LL_3\} \quad (3)$$

$$\beta = \{C(x, y) \mid (x, y) \text{ in } LH_3, HL_3, HH_3\} \quad (4)$$

$$\gamma = \{C(x, y) \mid (x, y) \text{ in } LH_2, HL_2, HH_2, LH_1, HL_1, HH_1\} \quad (5)$$

As the follow, there are distinct concepts and ways of these partitions.

A. For $\alpha = \{C(x, y) \mid (x, y) \text{ in } LL_3\}$

Each recursion in original SPIHT algorithm must send a bit map *C(x, y)* in LL_3, descend the threshold value from T_0 to T_1($T_1=T_0/2$), and decrease the reconstructive value from R_0 to R_1 ($R_1=R_0/2$). Both threshold value T and reconstructive value R are geometric progression. To reduce the encoding bits, it is essential to decrease threshold value. Threshold value T_1 was changed from $T_0/2$ into $T_0/4$ in each recursion. It is also a geometric progression. Meanwhile, if the reconstructive value R is changed from $T_0/2$ into $T_0/4$, the exact value would be unbalance distribution. To avoid this phenomenon, the reconstructive value R should be calculated by $R_1=(T_1+R_0)/2$, and the exact value would become balance distribution. The reduction of recursive number gains quite compression advantage, the bit rate reduces 0.05~0.1 bpp (bit per pixel).

B. For $\beta = \{C(x, y) \mid (x, y)$ in $LH_3, HL_3, HH_3\}$

The modified SPIHT algorithm use a set *w* to reduce the redundancy in the partition β. The original SPIHT algorithm does not think about correlation in the same level subband. The modified SPIHT algorithm adopts a set *w*, and *w* records what subband between LH_3, HL_3 and HH_3 has significant coefficient. The modified SPIHT algorithm adopts a set *w* to eliminate the correlation in the same level subbands.

$$w = \{ w(x, y) \mid LH_3(x, y) \cup HL_3(x, y) \cup HH_3(x, y)\} \quad (6)$$

The partition *w* must be send to decoder. If $w(x, y)=1$, the bits of $LH_3(x, y)$, $HL_3(x, y)$,and $HH_3(x, y)$ would be send to the decoder, not like the original SPIHT send all the bit of $LH_3(x, y)$, $HL_3(x, y)$, and $HH_3(x, y)$. If $w(x, y)=0$, nothing to be sent to decode. The method can reduce about 0.1~ 0.2 bpp at the same PSNR (peak signal to noise ratio) value.

C. For $\gamma = \{C(x, y) \mid (x, y)$ in $LH_2, HL_2, HH_2, LH_1, HL_1, HH_1\}$

The modified SPIHT algorithm proposes dictator to reduce the redundancy in the partition γ. The significant coefficients in this partition are few, and the original SPIHT algorithm suggested that using one bit to present whether the significant coefficient is in the quadtree or not. There is at least one significant coefficient in the quadtree. And it presented as 1. If all of the nodes in the quadtree are the insignificant coefficients, it presented as 0. There is quite large correlation in these subbands that original SPIHT algorithm neglected, the modified SPIHT algorithm proposes dictator to solve this problem. According to the quadtree concept, we know that there is a correction between LH_1 and LH_2, as the same reason in HL_2, HL_1, HH_2, and HH_1. Therefore, we divide LH_2, LH_1, HL_2, HL_1, HH_2, and HH_1 into three partitions Q_t, $t=1, 2,$ and *3*.

$$Q_1=\{ LH_2 \cup LH_1 \} \quad (7)$$

$$Q_2=\{ HL_2 \cup HL_1 \} \quad (8)$$

$$Q_3=\{ HH_2 \cup HH_1 \} \quad (9)$$

We defined the set S_u, u=1, 2, and 3. The set S_u describes that the subtrree coefficients in Q_t is significant or insignificant. S_1 is modified by following conditions in the set Q_1.

$$S_1(I, J)= 1, \text{ if } LH_1(x, y)=1, I=\lfloor x/4 \rfloor \text{ and } J=\lfloor y/4 \rfloor. \quad (10)$$

$$S_1(I, J)= 1, \text{ if } LH_2(x, y)=1, I=\lfloor x/2 \rfloor, \text{ and } J=\lfloor y/2 \rfloor. \quad (11)$$

$$S_1(I, J)= 0, \text{ otherwise}. \quad (12)$$

There are the same steps in Q_2 and Q_3, and they result in S_2 and S_3. Because of the higher correlation between three sets (S_1, S_2, S_3), the modified SPIHT algorithm creates a dictator that points out what subband had significant coefficients. And the dictator *d* will decide what needs to send or not.

$$d=\{d(m, n) \mid T_1(m, n) \cup T_2(m, n) \cup T_3(m, n)\} \quad (13)$$

Figure 3 shows the concept and framework of the dictator. The oblique line block is the set S_u, *u=1, 2, and 3.* This way even economized the bit to present the insignificant coefficients.

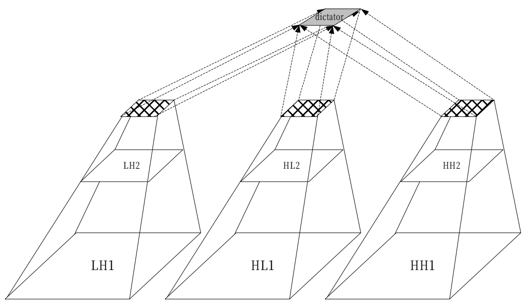


Figure 3. The dictator concepts and framework.

According to the information of *d*, we can find what subband has significant coefficients. And we classify these subbands that have significant coefficients into seven types. According to the significant coefficients in different subbands, we encode differently.

Seven types are as follow, (the LH means LH_1 or LH_2, HL means HL_1 or HL_2, HH means HH_1 or HH_2).

Type 1: the significant coefficients are in LH.

Type 2: the significant coefficients are in HL.

Type 3: the significant coefficients are in HH.

Type 4: the significant coefficients are in LH and HL.

Type 5: the significant coefficients are in LH and HH.

Type 6: the significant coefficients are in HL and HH.

Type 7: the significant coefficients are in LH, HL and HH.

For example, Type 6 is the significant coefficients in HL and HH. So we encode the bitmap of LH and HH to show the significant coefficient position. And we encode the sign of significant coefficient.

4. Simulation result

Sonogram medical images are selected as test data. It is gray-level image with a size of 512 x 512 with 8 bits per pixels. We compare our propose algorithm with JPEG 2000 that adopts original SPIHT and TCQ (trellis coded quantization) [6]. The performance is evaluated by PSNR (peak signal to noise ratio) value. PSNR value is a mathematics evaluation expression that can be calculated as

$$\mathrm{PSNR} = 10\log_{10}\frac{255^2}{\frac{1}{T}\sum_{i=0}^{n-1}\sum_{j=0}^{n-1}\left(x_{i,j}-x'_{i,j}\right)^2} \quad (14)$$

PSNR value has been accepted as a widely used quality measurement in the field of image compression.

The test images are showed in Figure 4. Figure 4(a) is a sonogram image with text. This property of the image raises the difficulties of compression and different with the other images. Even so, the decoded quality of texts and electrocardiogram (ECG) waveforms is still acceptable to diagnose, as show in Figure 4(c), a decoded by modified SPIHT electrocardiogram image at the bit rate of 1.4 bpp with the PSNR value of 43.3 dB. Figure 4(b) shows a decoded by JPEG 2000 electrocardiogram image at the bit rate of 1.4 bpp with the PSNR value of 40.6 dB. Figure 4(d) shows that the different image between Figure 4(a) and Figure 4(c) has no intention.

Table 3. Performance of proposed method.

Bit rate (bpp)	PSNR of Original SPIHT (dB)	PSNR of JPEG2000 (dB)	PSNR of Modified SPIHT (dB)
0.35	31.5	34.5	35.0
0.80	37.4	37.9	38.4
1.40	41.2	40.6	43.3
2.77	49.3	48.00	50.6

In Table 3, the PSNR values at different bit rate are listed in comparison with original SPIHT, JPEG 2000 and modified SPIHT. At the same bit rate, the modified SPIHT PSNR values are absolutely higher than these of original SPIHT and JPEG 2000. The test images (Figure 2) are several kinds of medical images include angiogram image, sonogram image and X-ray image. Figure 5 illustrate the PSNR values of our proposed method is better than the PSNR values of JPEG2000, and ref. [9] at the same bit rate in several kinds of medical images.

5. Conclusions

In the paper, we introduce that original SPIHT algorithm is proposed to achieve good performance, and the modified SPIHT is modified from original SPIHT according to the medical image characteristic. This is the first technique employed SPIHT to compress the medical images. The main goal of this paper is to find a bit-rate reduced method that can save the store usage and achieve fast transmit of the distance diagnosis in the future. Those modified SPIHT reduce the redundancy more than original SPIHT and JPEG2000. And the modified SPIHT is more suitable for compression of medical images than JPEG 2000.

Acknowledgement

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Figure 4 (a)

Figure 4 (b)

Figure 4 (c)

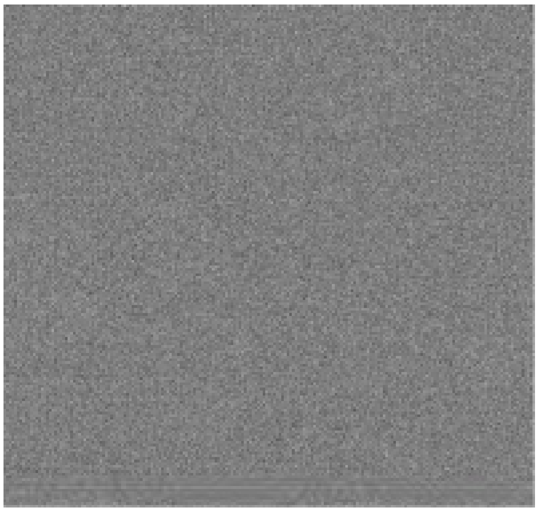

Figure 4 (d)

Figure 4: Sonogram test image

(a) Original test image

(b) Compressed by JPEG2000, bit rate=1.4 bpp, PSNR value=40.6 dB

(c) Compressed by modified SPIHT, bit rate=1.4 bpp, PSNR value=43.3 dB

(d) Difference image between Figure 4(a) and Figure 4(c)

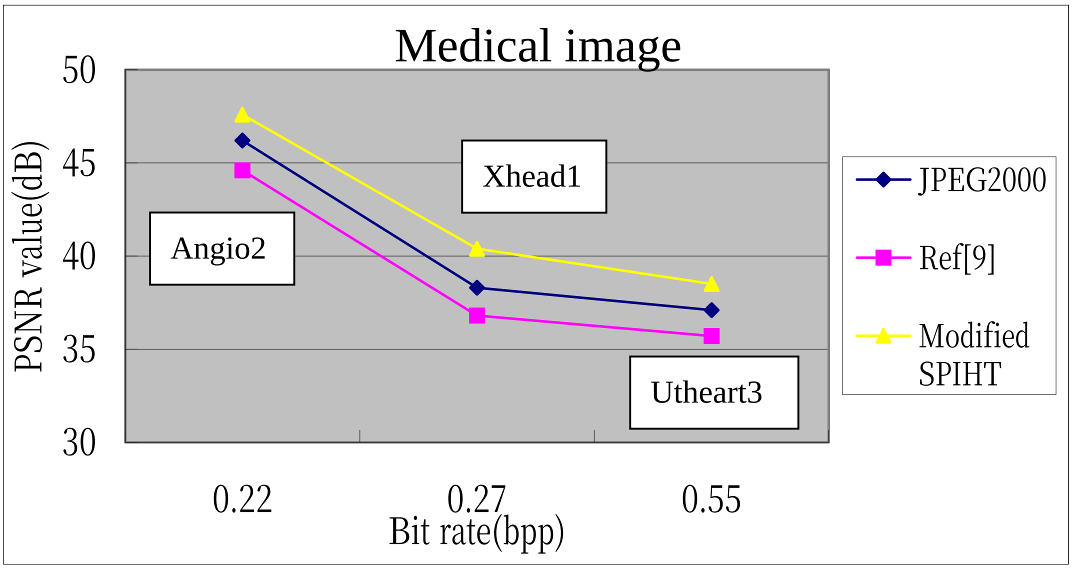

Figure 5: Illustration the PSNR value in several kinds of medical images