

Enhanced Image Compression Algorithm for Image Processing Applications

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Abstract-Due to the increasing traffic caused by multimedia information and digitized form of representation of images; image compression has become a necessity. New algorithms for image compression based on wavelets have been developed which offers considerable improvement in picture quality at high compression ratios. To achieve lowest errors per compression rate and highest perceptual quality, the existing image compression algorithms are need to be modified. In this paper, with the objective of achieving high image compression ratio with minimum number of errors, the features of existing image compression algorithms like Haar Wavelet Transform are increased and named as Modified Fast Haar Wavelet Transform (MFHWT). The Set Partitioning In Hierarchical Trees (SPIHT) along with Run Length Encoding (RLE) increases the compression ratio without degrading the image quality. Also, the modified algorithm reduces the number of computations in Haar transform, which decreases the processing time. The proposed work was simulated using MALAB and the results shows that the compression ratio increases without affecting the Peak Signal to Noise Ratio (PSNR) standards.

Keywords- Image Compression, DWT, MFHWT, ESPIHT, RLE

1. INTRODUCTION

The uncompressed multimedia like graphics, audio and video data requires large storage capacity and transmission bandwidth despite rapid progress in mass storage density, processor speed, digital communication system performance and data transmission bandwidth continues to exceed the capabilities of available technologies. The recent growth of data demanding multimedia-based web applications have not only the need for more competent ways to encode signals and images but have made compression of such signals central to storage and communication technology. The Table 1 shows multimedia data types and uncompressed storage space, transmission bandwidth and transmission time required. The Table 1 clearly illustrates the need for sufficient storage space, large transmission bandwidth and long transmission time for image, audio and video data. At the present technology, the only solution is to compress multimedia data before its storage and transmission, and decompress it at the receiver for playback [1].

Table 1. Multimedia data

Multi-media data	Size or duration	Bits/ pixel (or) Bits/sample	Un-Compressed size (B-bytes)	Transmission Band-width (b-bits)	Transmission Time (28.8 k Modem)
Page of text	11" x 8.5"	Varying resolution	4.8KB	32-64 Kb/page	1.1-2.2 Secs
Telephone Quality speech	10 Secs	8 bps	80 KB	64 Kb/Sec	22.2 Secs
Gray scale image	512 x 512	8 bpp	262 KB	2.1 Mb /image	1 min 13 Secs
Color image	512 x 512	24 bpp	786 KB	6.29 Mb /image	3 min 39 Secs
Medical image	2048 x 2048	12 bpp	5.16 MB	41.3 Mb /image	23 min 54 secs

1.1 Image Compression

The main aim of the Image compression is to reducing the number of bits required to symbolize an image by removing the spatial and spectral redundancies as much as possible. In many different fields, digitized images are used as photograph or x-rays rather than analog images. The volume of data needed to describe such images greatly slow transmission and makes storage prohibitively costly. Therefore the information contained in images must be compressed by extracting only visible elements, which are then encoded. To increase the compression of the data to represent an image substantially, the quantity of data is reduced. The essential goal of image compression is to reduce the bit rate for transmission or storage while maintaining an acceptable reliability or image quality. Wavelet-based coding provides a considerable improvement in picture quality at privileged compression ratios. Over the past few years, a variety of powerful and sophisticated wavelet-based schemes for image compression have been developed and implemented. A wavelet basis consists of functions with both short support (for high frequencies) and long support (for low frequencies). Because of the many advantages, wavelet based compression algorithms are the suitable for the new JPEG-2000 standards. Transform-based image compression is one of the most successful applications of wavelet methods. Such a coder operates by transforming the data to remove redundancy, then quantizing the transform coefficients (a lossy step), and finally entropy coding the quantizer output. The loss of information is introduced by

the quantization stage which intentionally discards less related parts of the image information [1]. Over the past few years, a variety of novel and sophisticated wavelet-based image coding schemes have been developed. They are

- Embedded Zero tree Wavelet (EZW),
- Set-Partitioning in Hierarchical Trees (SPIHT),
- Set Partitioned Embedded block coder (SPECK),
- Wavelet Difference Reduction (WDR),
- Adaptively Scanned Wavelet Difference Reduction (ASWDR),
- Space –Frequency Quantization (SFQ),
- Compression with Reversible Embedded Wavelet (CREW),
- Embedded Predictive Wavelet Image Coder (EPWIC),
- Embedded Block Coding with Optimized Truncation (EBCOT),
- Stack- Run (SR).

SPIHT introduced in [13] is an enhancement of EZW algorithm. By adopting set partitioning algorithm and exploring self-similarity across different scales in an image wavelet transform, SPIHT algorithm reaches high compression performance. With SPIHT, the image is first decomposed into a series of wavelet coefficients. Those coefficients are then grouped into sets known as spatial orientation trees. After that, the coefficients in each spatial orientation tree are encoded progressively from the most significant bit planes to the least significant bit planes, starting with the coefficients with the highest magnitude [14].

As with EZW, the SPIHT algorithm involves two coding passes: the sorting pass and the refinement pass. The sorting pass looks for zerotrees and sorts significant and insignificant coefficients with respect to a given threshold. And the refinement pass sends the precision bits of the significant coefficients. After one sorting pass and one refinement pass, which can be considered as one scan pass, the threshold is halved, and the coding process is repeated until the expected bit rate is achieved. SPIHT achieves very compact output bit stream and low bit rate than that of its predecessor's EZW without adding an entropy encoder, which allows its efficiency in terms of computational complexity. Moreover, it uses a subset partitioning scheme in the sorting pass to reduce the number of magnitude comparisons, which also decrease the computational complexity of the algorithm. Finally, the progressive mode of SPIHT allows the interruption of coding/decoding process at any stage of the compression [2]. Despite these advantages, SPIHT presents the limitations like large memory and delay shortcomings. To minimize these limitations, a novel technique is proposed by enhancing the SPIHT algorithm with the combination of Run Length coding for image compression.

The rest of this paper is organized as follow. The next section, Section2, gives an outline of the related works on image compression. The Section 3 gives the objective of the proposed algorithm. The ESPIHT algorithm is

explained in Section 4. Section5 shows results on the performance metrics and provides comparisons with the SPIHT coder. Finally Section 6 concludes the paper.

2. LITERATURE SURVEY

The authors Albertus Joko Santoso *et al.* considered the test images of size 512x512 and analyzed with different wavelets like Daubechies, Coiflet and Symlet with the objective of achieving high PSNR and compression ratio. The result analysis proved that Haar wavelet attains highest Compression Ratio and PSNR than Coiflet and Symlet wavelets [3].

The authors S.Narasimhulu *et al.* proposed lossy image compression algorithm which is simple and effective for gray-scale image compression with the combination of Huffman coding and proposed to extend the work for the color image and video compression [4].

Anuj Bhardwaj *et al.* compared different image compression techniques like Haar Transform (HT), Fast Haar Transform (FHT), and Modified Fast Haar Wavelet Transform (MFHWT) on the basis of the Compression Ratio and PSNR. The results illustrates that the MFHWT has characteristics like sparse representation and fast transformation and easy to implement. The comparison results showed that the quality of reconstructed image is high in MFHWT [5].

Kiran Arora *et al.* compared the image compression algorithms HT, FWT, MFHWT on the basis of processing time. The results showed that the time taken by MFHWT is least as compared to HT and FHT while compression [6]. The authors Navjot Kaur *et al.* proposed a new method of image compression using SPIHT and MFHWT and they do not implement [7]. The authors Ms.MansiKambli *et al.* proposed a modified SPIHT algorithm and implemented on gray scale fingerprint images to analyze the PSNR vales [8].

3. PROBLEM STATEMENT

The objective of this work is to minimize the memory requirement by achieving high compression ratio without degrading the quality of image by using both lossy and lossless compression techniques. Also, the compression techniques reduce the delay and consume less power by transmitting the compressed data. The compressed information resembles a scramble message and an attacker in middle cannot able to understand. Therefore, the data compression not only reduces the size of the original data, but also gives data security.

4. OVER VIEW OF PROPOSED METHOD

The block diagram of the proposed work is shown in the Figure 1. The original image is compressed using Enhanced Set-Partitioning in Hierarchical Trees (ESPIHT) image compression technique which is the combination of Modified Fast Haar Wavelet Transform (MFHWT) & SPIHT and lossless Run Length coding (RLC) techniques. At receiver the compressed image is decompressed by reverse operation.

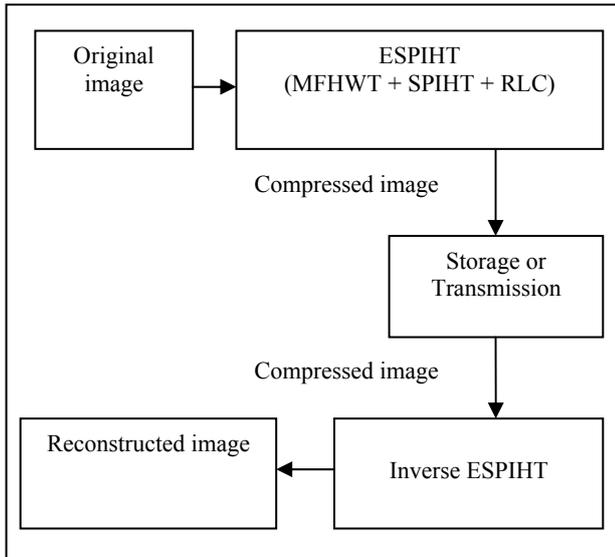


Fig 1: Block diagram for proposed system

This section provides overview of the proposed algorithm and in this algorithm MFHWT is combined with SPIHT to enhance the compression ratio without losing information. The Figure 2 is the flow chart of the proposed work.

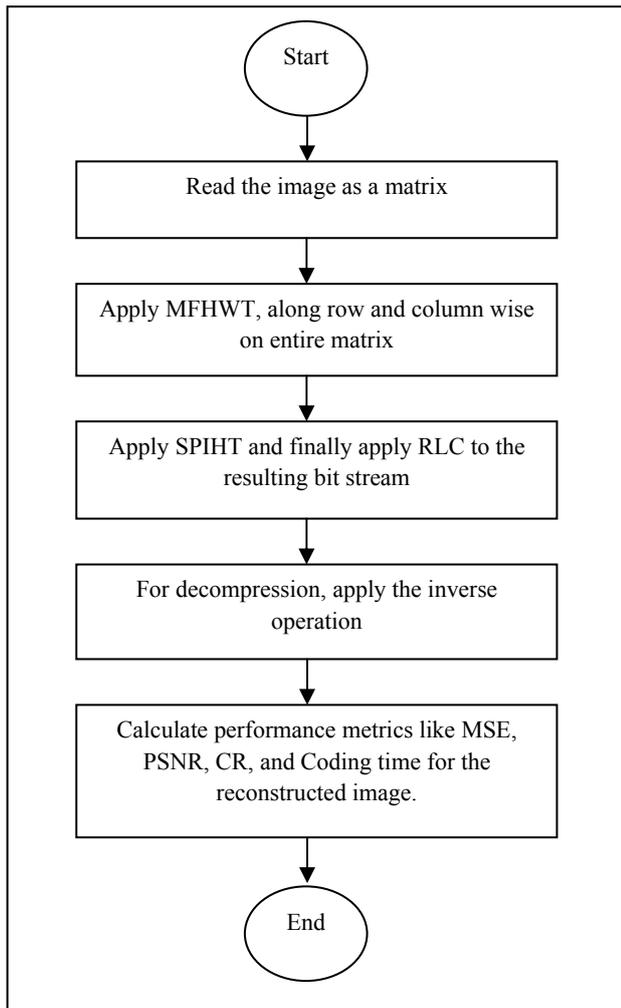


Fig 2: Flow chart of proposed algorithm

4.1 Modified Fast Haar Wavelet Transform (MFHWT)

Modified Fast Haar Wavelet Transform (MFHWT), is one of the algorithms which can lessen the computation work in Haar Transform (HT) and Fast Haar Transform (FHT). Modified Fast Haar Transform not only allows certain calculation in the process decomposition be overlooked without affecting the results, but also still remains in simple type of calculation as for FHT. The MFHWT works based on the idea that approximate coefficients can be ignored since it is not involve in the reconstruction work as well as threshold process in multi-resolution wavelet analysis. As FHT, we use 2^N data. For Modified Fast Haar Transform, MFHWT, it can be done by just taking $(w+ x + y + z)/ 4$ instead of $(x + y)/ 2$ for approximation and $(w+ x - y - z)/ 4$ instead of $(x - y)/ 2$ for differencing process. 4 nodes have been considered at once time. Notice that the calculation for $(w+ x - y - z)/ 4$ will give up the detail coefficients in the level of $n - 2$. In MFHWT, for data of size $2N$, the approximations are calculated as

$$\frac{x_{4i}+x_{4i+1}+x_{4i+2}+x_{4i+3}}{4}, \text{ where } i = 0, 1, \dots, \frac{1}{4}(2^N)$$

and detail sub signal at the same level is given as

$$\frac{x_{4i}+x_{4i+1}-x_{4i+2}-x_{4i+3}}{4}, \text{ where } i = 0, 1, \dots, \frac{1}{4}(2^N)$$

For the purpose of getting detail coefficients, still the differencing process between two nodes $(x - y)/ 2$ need to be done. The Figure 2 shows the calculation of the Modified Fast Haar Wavelet Transform, MFHWT, for $n = 4$, given by the data $F = [2 \ 4 \ 6 \ 3 \ 1 \ 5 \ 9 \ 8 \ 7 \ 2 \ 4 \ 8 \ 1 \ 3 \ 9 \ 5]^T$. In MFHWT the decomposition can be done by using matrix formulation and get the values of approximation and detail coefficients one level (L) in advance than the FHT and HT (Figure 3).

At each level in MFHWT, we need to store only half of the original data used in FHT shown in the Figure 3, due to which it increases its efficiency. It is used to reduce the memory requirements and the amount of inefficient movement of Haar coefficients. The Table 2 shows the comparison between FHT and Modified Fast Haar wavelet transform in terms of the computation parameters for $N=8$.

Table 2. Comparison between FHT and MFHWT

Proce- dure	No of Addition/ Subtraction Operations	No of Multiplication/ Division Operations	No of Move- ments	No of Approx- imation coefficients
FHT	510	510	510	255
MFHWT	850	340	340	85

An important enlargement for the proposed MFHWT is the number of approximate coefficients can be reduced as well as number of division operations. This fulfils the target of trying to reduce the memory requirements of the transform and the amount of incompetent movement of Haar coefficients. The negative aspect in escalating the number of addition and subtraction operation is balanced by the diminishing in number of division operation as shown in the Table 2.

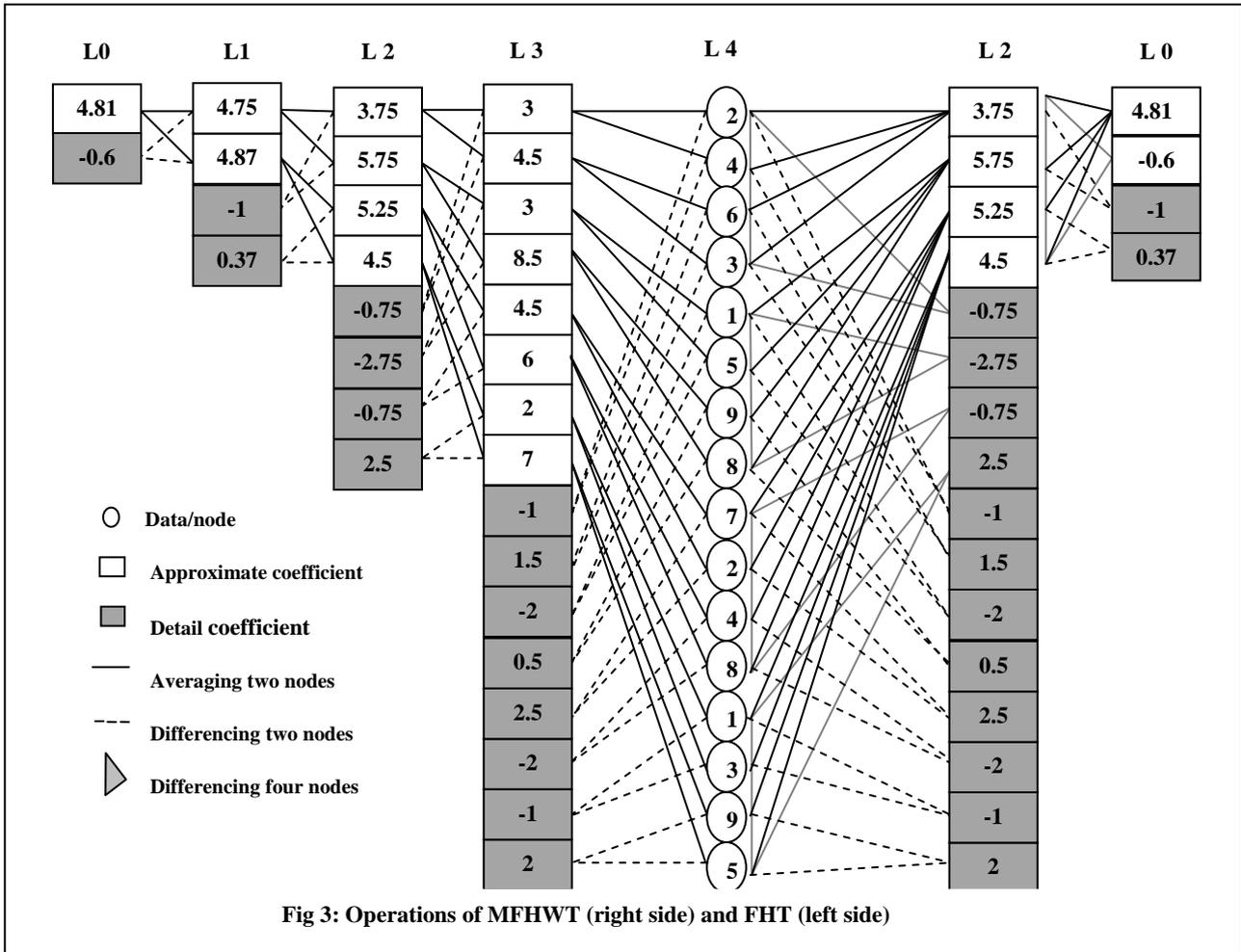


Fig 3: Operations of MFHWT (right side) and FHT (left side)

4.2 SPIHT Algorithm

SPIHT algorithm is based on Embedded Zero tree Wavelet (EZW) coding method and it uses set partitioning sorting algorithm. Coefficients corresponding to the same spatial location in different sub bands in the pyramid structure exhibit self-similarity characteristics. SPIHT defines parent children relationships between these self- similar sub bands to establish spatial orientation trees [10].

The terms and notations are used in SPIHT algorithm is shown here, as

- $C(i, j)$: wavelet transformed coefficient at coordinate (i, j) .
- $O(i, j)$: set of coordinates of all offspring of node (i, j) ; children only.
- $D(i, j)$: set of coordinates of all descendants of node (i, j) children, grandchildren, great-grand, etc.
- $L(i, j)$: set of coordinates of all leaves of node (i, j) . $L(i, j) = D(i, j) - O(i, j)$ grandchildren, great-grand, etc..
- $H(i, j)$: set of coordinates of all nodes in the coarsest level of wavelet coefficient pyramid; parents
- $S_n(i, j)$: significance test of a set of coordinates $\{(i, j)\}$ at

bit plane level n

$$S_n(i, j) = \begin{cases} 1 & \text{if } \max_{\{(i,j)\}} \{|C(i,j)|\} \geq 2^n \\ 0 & \text{otherwise} \end{cases}$$

- Type A sets: for sets of type A the significance tests

are to be applied to all descendants.

- Type B sets: for sets of type B the significance tests are to be applied only to the leaves.

The flow chart of SPIHT Algorithm is shown in the Figure 4.

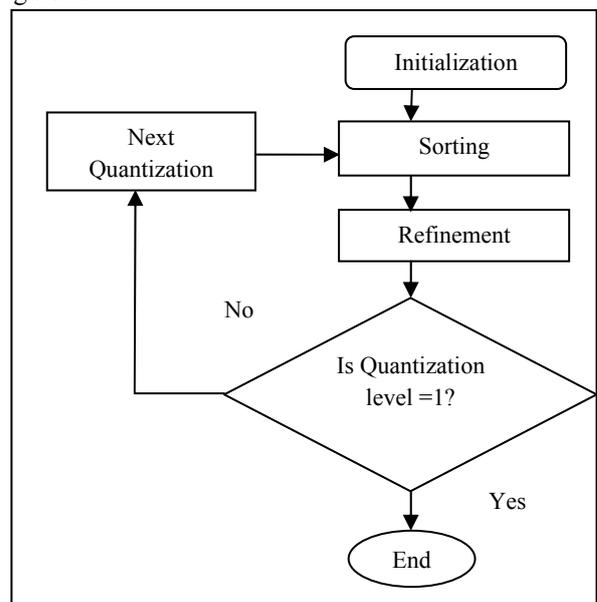


Fig 4: Flow chart of ESPIHT Algorithm

4.2.1 SPIHT Algorithm steps:

- 1) Initialization: At the initialization stage first define the number of decomposition levels indicated by n using the following Eq.(1).

$$n = \lceil \log_2(\max_{\{i,j\}}\{C(i,j)\}) \rceil \quad (1)$$

Then set the threshold value indicated by $T = 2^n$; after then set the List of Significant Pixels (LSP) as an empty list, and position the coordinates in the coarsest level of wavelet coefficient pyramid to the List of Insignificant Pixels (LIP), and those which have descendants moved to the List of Insignificant Sets (LIS) as type A entries.

- 2) Sorting Pass: In sorting pass there are two steps as follows

(i) Assessment of List of Insignificant Pixels

In the sorting pass, the first step is to examine List of Insignificant Pixels. In this step the LIP is scanned to find out whether an entry coefficient is significant at the current threshold or not. If an entry is found to be significant, then output a bit 1 and another bit is used to represent the sign of the coefficient, which is marked by either 1 for positive or 0 for negative. Now the significant coefficient is moved to the LSP. If an entry is found to be insignificant, then the output is 0 bit followed by another bit for the sign of the coefficient.

(ii) Assessment of List of Insignificant Sets

The second step of sorting pass is to examine the entries in LIS. First check the entry is type A or type B. When an entry is the set of all descendants of a coefficient, named type A, then apply the magnitude tests for all descendants of the current entry is passed out to decide whether they are significant or not. If the entry is found to be as significant, the direct offsprings of the entry undergoes magnitude tests. If direct offspring is significant, it is moved into LSP; otherwise it is moved into LIP similar to the previous step. If the entry is found to be insignificant, a bit 0 is output and no further processing is needed. Finally, this insignificant entry is moved to the end of LIS as type B, which is the set of all descendants except for the immediate offspring (children) of a coefficient. If the entry in LIS is type B, significance test is performed on the descendants of its direct offsprings. If significance test is true, the spatial orientation tree with root of type B entry is split into four sub-trees that are rooted by the direct offspring and these direct offsprings are added in the end of LIS as type A entries and remove this entry as type B in the LIS. The imperative thing in LIS sorting is that entire sets of insignificant coefficients are represented with a single zero [10].

- 3) Refinement pass: it is used to output the refinement bits (n^{th} bit) of the coefficients in LSP at current threshold. Before the algorithm proceeds to the next round, the current threshold is halved that is $T/2$.
- 4) Quantization-Step Update: decrement n by 1 and go to step 2. This process is going on until the last quantization level will be equal to 1.

4.3 Run Length Coding (RLC)

Run-length coding is probably the simplest method of compression. The general idea behind this method is to replace consecutive repeating occurrences of a symbol by one occurrence of the symbol followed by the number of occurrences. Individual channel matrices were retrieved and used for processing. Firstly each matrix was scanned row wise for identifying repetitive pixels. Each group of such repetitions was then replaced by the pixel value and the frequency of occurrence. This was done exhaustively throughout the image matrix. For single occurrence of a particular value frequency was not used because that would cause an overhead affecting the compression efficiency. Sample processing example:

Input stream: 22 22 22 57 57 57 33 33 33 33 33 22

Output stream: 322 457 533 22

The output stream produced a series of frequency-pixel value pairs and this new representation of original matrix information for individual matrices was forwarded to the next section for processing [12].

5. IMPLEMENTATION AND RESULT ANALYSIS

The proposed algorithm is simulated using MATLAB on different color images of 512 X 512 sizes with the following metrics to evaluate the image quality.

5.1 Mean Square Error (MSE):

It refers to some sort of average or sum (or integral) of squares of the error between two images as shown in the Eq. (2).

$$MSE = \frac{1}{MN} \sum_{x=1}^M \sum_{y=1}^N [I(x, y) - I'(x, y)]^2 \quad (2)$$

Where $I(x, y)$ is the original image data and $I'(x, y)$ is the compressed image data.

5.2 Peak Signal to Noise Ratio (PSNR):

It is defined as the ratio between signal variance and reconstruction error variance. Peak Signal to Noise Ratio and Compression Ratios are calculated from the following Eq.(3).

$$PSNR = 10 \log_{10} \left(\frac{MAX_I^2}{MSE} \right) \quad (3)$$

Where MAX_I is the maximum size of the image

5.3 Compression Ratio (CR):

Compression ratio is defined as the ratio between the original image size (n_1) and compressed image size (n_2) as in Eq.(4).

$$CR = n_1/n_2 \quad (4)$$

5.4 Coding Time:

It is the total time taken for the image compression and decompression.

The Figure 5 shows that the original image and reconstructed images of SPHIT and ESPHIT algorithms. The performance of the two algorithms was assessed using error metrics on the test images. The quality of the reconstructed images is measured in terms of PSNR value and the efficiency of the proposed method is measured in terms of its compression ratio.

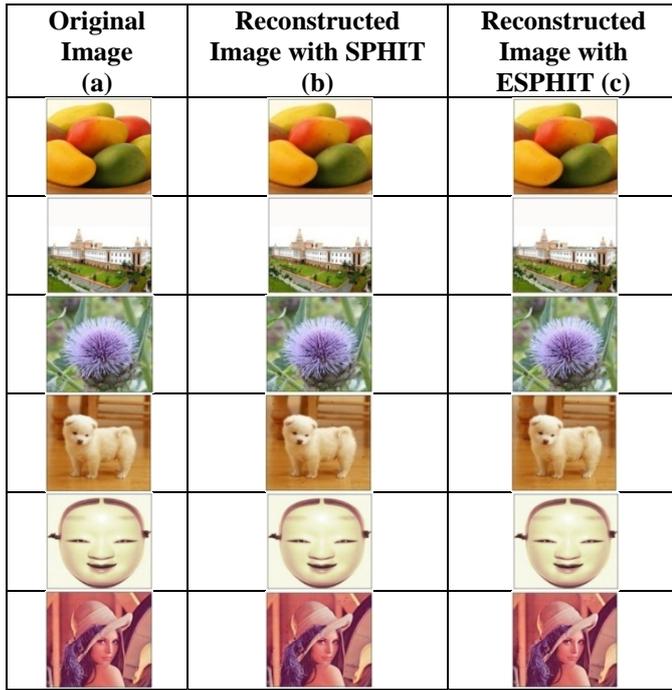


Fig 5: Results of image compression
(a) Original image (b) SPIHT and (c) ESPIHT algorithms

The analysis shows that the proposed algorithm reduces the computational complexity and in turn reduces the execution time with high PSNR. The Table 3 shows the comparison between two image compression techniques with different performance metrics.

Table 3. Experimental Results

Image	Using SPIHT		Using ESPIHT	
	PSNR (dB)	Coding Time (Sec)	PSNR (dB)	Coding Time (Sec)
Image 1	41.7	0.748	43.78	0.615
Image 2	40.85	2.062	42.57	1.091
Image 3	38.96	0.766	40.51	0.632
Image 4	40.31	0.989	41.95	0.732
Image 5	44.16	0.976	47.87	0.721
Image 6	38.49	0.628	40.27	0.574

Image	Using SPIHT		Using ESPIHT	
	MSE	Compression ratio (%)	MSE	Compression ratio (%)
Image 1	4.397	30.06	2.72	52.78
Image 2	5.347	46.96	3.599	63.17
Image 3	8.262	44.83	5.776	70.20
Image 4	6.058	32.34	4.155	55.74
Image 5	2.497	32.68	1.062	53.87
Image 6	9.317	54.93	6.113	84.78

Figure 6 shows, the Mean Square Error (MSE) calculated for different images using SPIHT and ESPIHT algorithms. The number of images which are compressed using SPIHT and ESPIHT are plotted on the x-axis, where as MSE is plotted on the y-axis. It is observed that ESPIHT has lowest Mean Square Error as compared to SPIHT coding for all six test images considered and proved that it can maintain good quality of image.

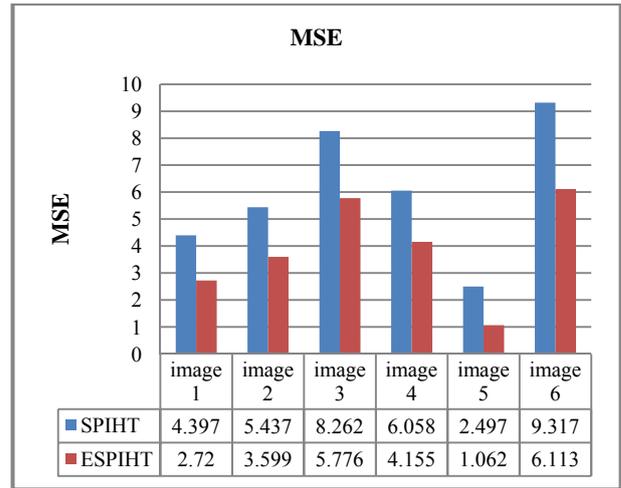


Fig 6: Analysis of MSE

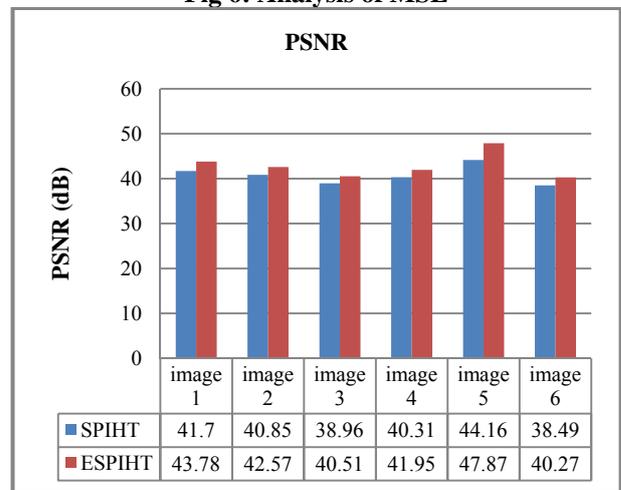


Fig 7: Analysis of PSNR

Figure 7 shows, the PSNR calculated for different images using SPIHT and ESPIHT algorithms. The number of images which are compressed using SPIHT and ESPIHT are plotted on the x-axis, where as PSNR is plotted on the y-axis. It is observed that ESPIHT has highest PSNR as compared to SPIHT coding for all six test images considered and proved that the quality of reconstructed image in case of ESPIHT coding is highest.

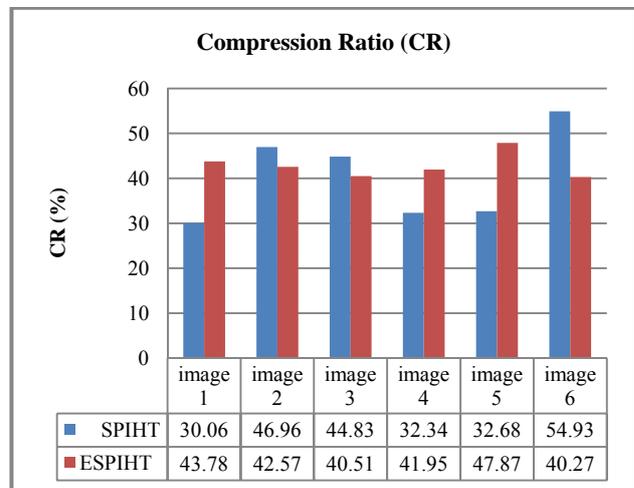


Fig 8: Analysis of Compression Ratio

Figure 8 shows, the Compression ratio calculated for different images using SPIHT and ESPIHT algorithms. The number of images which are compressed using SPIHT and ESPIHT are plotted on the x-axis, where as Compression ratio is plotted on the y-axis. It is observed that ESPIHT has highest Compression ratio as compared to SPIHT coding for all six test images considered and proved that the ESPIHT is better technique for compression. From Figure 9 it is observed that ESPIHT has lowest values for Coding Time as compared to SPIHT coding in all six types of test images taken.

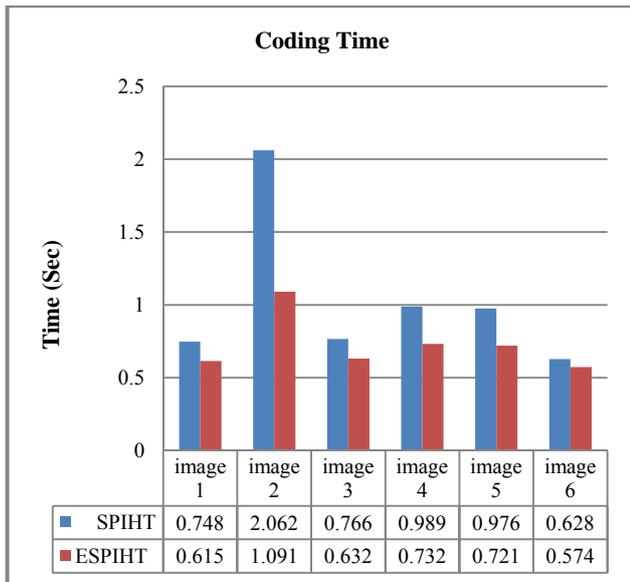


Fig 9: Analysis of processing time

6. CONCLUSION

In this work, ESPIHT algorithm which is efficient for compression is implemented and simulated successfully using MATLAB. The simulation results have shown that ESPIHT gives better compression ratio as compare to SPIHT without degrading the image quality and takes less time for compression using MFHWT. In future SPIHT can also be implemented for lossless image compression for higher image quality i.e. high PSNR without much decrease in compression ratio.

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