Lifting Scheme Using HAAR & Biorthogonal Wavelets For Image Compression

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ABSTRACT

The objective of this paper is to evaluate two wavelets (HAAR & Biorthogonal) for image compression & to compare their performance with Lifting Wavelet Transform (LWT). LWT is probably the best-known algorithm to calculate the wavelet transform in a more efficient manner & provides faster implementation of DWT. This paper describes Lifting scheme using HAAR & Biorthogonal wavelets. Image quality is measured in terms of Peak-signal-to-noise ratio (PSNR), Signal to noise ratio SNR, Mean squared error (MSE), Energy Retained (ER), Execution time and Percentage of Zeros.

***Keywords* -** DWT, Image compression, LWT, LSHAAR, LSBIOR.

I. Introduction

Demand for communication of multimedia data through the telecommunications network and accessing the multimedia data through Internet is growing explosively. With the use of digital cameras, the requirements for manipulation, storage, and transfer of digital images, has grown. These digital image files can be very large and can occupy a lot of memory. So images must be compressed before transmission and storage. A typical still image contains a large amount of spatial redundancy in plain areas where adjacent picture elements (pixels, pels) have almost the same values. Meaning that, the pixel values are highly correlated. In addition, a still image can contain spectral redundancy, which is determined by properties of a human visual system (HVS) [10].Transform coding is a widely used method of compressing image information. In case of transform-based compression [5] system two-dimensional images are transformed from the spatial domain to the frequency domain. An effectual transform will concentrate useful information into a few of the low-frequency transform coefficients. HVS is more sensitive to energy component with low spatial frequency than with high spatial frequency [9]. Therefore, compression can be achieved by quantizing the coefficients, so that important coefficients (low-frequency coefficients) are transmitted and the remaining coefficients are discarded. Current standards for compression of images use DCT [3] [11]. The Discrete Cosine Transform (DCT) was first proposed by Ahmed et al. (1974) [3]. DCT coefficients measure the contribution of the cosine functions at different discrete frequencies. It provides excellent energy compaction [11]. In DCT, the image is divided into blocks of $N \times N$ samples and each block is transformed independently to give $N \times N$ coefficients. Despite all the advantages of JPEG compression schemes based on DCT namely availability of special purpose hardware for implementation satisfactory performance and simplicity [3], these are not without their shortcomings. In DCT, images are broken into blocks. The problem with these blocks is that when the image is reduced to higher compression ratios, these blocks become visible. This is termed as the “blocking effect” [3]. To solve this problem wavelet based compression system is used. In a wavelet compression system, the entire image is transformed and compressed as a single data object rather than block by block as in a DCT-based compression system. DWT [2] [4] (Discrete Wavelet Transform) allows a uniform distribution of compression error across the entire image [3]. So it is free from “blocking effect”. It offers adaptive spatial-frequency resolution (better spatial resolution at high frequencies and better frequency resolution at low frequencies) that is well suited to the properties of an HVS [9]. It can provide better image quality than that of DCT, especially on a higher compression ratio [8]. The main disadvantage of calculating DWT is its complexity which depends on the length of wavelet filters [8] [5]. Further the Lifting Wavelet Transform (LWT) [4] [7] [13] has been introduced for the efficient computation of DWT. Wavelet using the lifting scheme significantly reduces the computation time, speed up the computation process. The lifting transform even at its highest level is very simple. In this paper lifting scheme (LS) [13] is applied to HAAR and Biorthogonal wavelets.

II. Discrete Wavelet Transform (DWT)

Discrete wavelet transform (DWT) have certain properties that makes it better choice for image compression. DWT is especially suitable for images having higher resolution. It possesses the property of Multi-resolution i.e., it represents image on different resolution level simultaneously [1]. The

resolution is determined by a threshold below which all fluctuations or details are ignored. Due to higher decor -relation property, DWT can provide higher compression ratios with better image quality [4]. DWT offers adaptive spatial-frequency resolution (better spatial resolution at high frequencies and better frequency resolution at low frequencies). Therefore, DWT has potentiality for good representation of image with fewer coefficients [5].
DWT Converts an input series into one low-pass wavelet coefficient series and one high-pass wavelet coefficient series (each of length n/2) given by:

$$H_1=\sum_{M=0}^{Y-1} x_{2i-1}\, S_m(Z) \quad (1)$$

$$L_1=\sum_{M=0}^{Y-1} x_{2i-1}\, t_m(Z) \quad (2)$$

Where $S_m(Z)$and $t_m(Z)$ are called wavelet filters, Y is the length of the filter, and i = 0, $(\frac{n}{2}$-1). In practice (1) and (2) is applied recursively on the low-pass series until a desired number of iterations are reached.

The most commonly used implementation of the discrete wavelet transform (DWT) consists of recursive application of the low-pass/high-pass [8] one-dimensional (1-D) filter bank successively along the horizontal and vertical directions of the image as shown in Fig. 1, thus splitting the image into four sub-bands referred as LL, HL, LH & HH (Approximation, Horizontal Detail, Vertical Detail, and Diagonal Detail respectively) [5].The low-pass filter provides the smooth approximation coefficients while the high-pass filter is used to extract the detail coefficients at a given resolution. Both low-pass and high-pass filters are called sub-bands. On original image, the number of decompositions performed to obtain sub bands is called sub-band decomposition level.

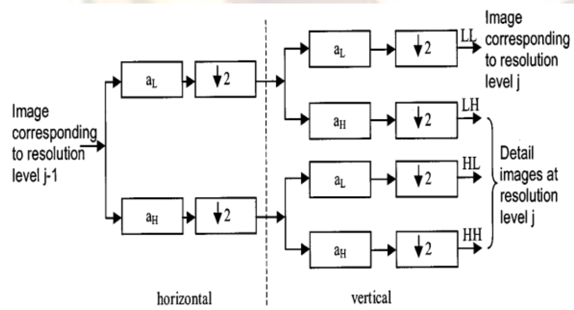

Figure1. One filter level in 2-D DWT

After the first level of decomposition, there are 4 sub-bands: LL_1, LH_1, HL_1, and HH_1. For each successive level of decomposition, the LL sub-band of the previous level is used as the input. To perform second level decomposition, the DWT is applied to LL_1 band which decomposes the LL_1 band into the four sub-bands: LL_2, LH_2, HL_2,and HH_2. To perform third level decomposition, the DWT is applied to LL_2 band which decompose this band into the four sub-bands: LL_3, LH_3, HL_3, HH_3. This results in 10 sub-bands per component. LH_1, HL_1, and HH_1 contains the highest frequency part present in the image tile, while LL_3 contains the lowest frequency part. The three-level DWT decomposition is shown in Fig. 2 [8].

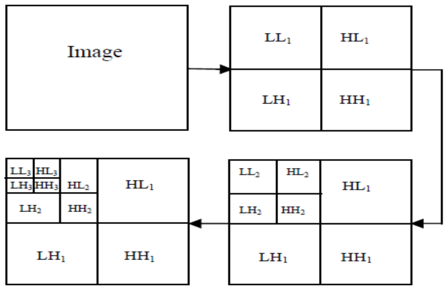

Figure2. Three level decomposition

In DWT implementation, the image decomposition is computed by means of a convolution filtering process and as the filter length increases, its complexity raises.

III. HAAR Wavelet

Any discussion of wavelets begins with HAAR wavelet [12], the first and simplest. HAAR Transform is orthogonal and real, results in a very fast transform [6]. HAAR wavelet is discontinuous, resembles a step function and represents the same wavelet as Daubechies db1. It is memory efficient, fast and exactly reversible without the edge effect [6]. The most distinctive feature of HAAR Transform lies in the fact that it lends itself easily to simple manual calculations.

For an input, represented by a list of numbers, the HAAR wavelet may be considered to simply pair up the input values, storing the difference and then passing the sum. This process is repeated recursively.

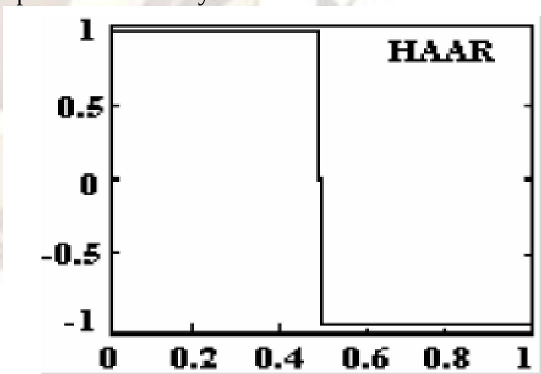

Figure3: HAAR Wavelet

IV. Biorthogonal wavelet

This family of wavelets exhibits the property of linear phase, which is needed for signal and reconstruction of image. By using two wavelets, one for decomposition (on the left side) and the other for reconstruction (on the right side) instead of the same single one, interesting properties are derived [2].

Analysis (decomposition) and synthesis (reconstruction) filter orders for Biorthogonal filters Specify the order of the analysis and synthesis filter orders for Biorthogonal filter banks as 1.1, 1.3, 1.5, 2.2, 2.4, 2.6, 2.8, 3.1, 3.3, 3.5, 3.7, 3.9, 4.4, or 5.5, 6.8. [10] Unlike orthogonal wavelets, Biorthogonal wavelets require two different filters one for the analysis and other for synthesis of an input. The first number indicates the order of the synthesis filter while the second number indicates the order of the analysis filter. The default is 1/1. In this paper 3/1 order is used which is shown in Fig.4.

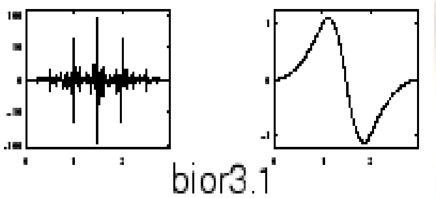

Figure4: Biorthogonal Wavelet

V. Lifting Wavelet Transform

The difference compared to classical wavelet construction is that it does not rely on the Fourier transform. Lifting scheme [1] is used to construct second-generation wavelets, which are not necessarily translations and dilations of one function. The lifting scheme [7] is probably the best-known algorithm to calculate the wavelet transform in a more efficient manner. Since it uses lesser no of filter coefficients than the equivalent convolution filter, it provide a faster implementation of DWT. [13]

Any DWT can be computed using lifting, and these transforms also reduce computational complexity when compared to classical filtering algorithms.

Lifting scheme is done by performing the following sequence of operations [7]:

1. Split a_j into Even-1 and Odd-1
2. $d_{j-1} = odd_{j-1} - Predict(even_{j-1})$
3. $a_{j-1} = even_{j-1} - Update(odd_{j-1})$

Lifting consists of three main steps [13]:

•**Split**: the original data is sub-sampled into odd half and even half sets.

•**Predict**: Predict constructs a prediction operator, which is typically based on a model of the signal data, to predict the missing parts from Split step. It determines the wavelet coefficients through a failure to predict the odd set based upon the even set. This step is also known as the **Dual Lifting** step. It is a high Pass filter.

•**Update**: This step updates the even set using the wavelet coefficients already determined to compute the scaling function coefficients, which maintains the needed properties among all the wavelet coefficients at all the levels. This step is also known as **lifting** step.

For the HAAR wavelet, we have the following steps [6]:

• Predict(x) = x
• Update(y) = y / 2

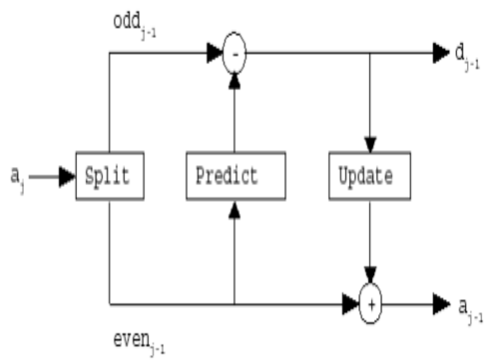

Figure5. Lifting scheme of forward wavelet transform

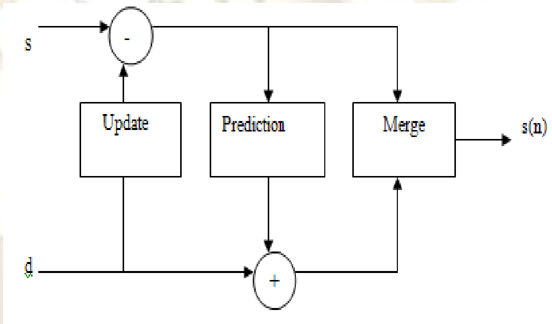

Figure6. Lifting scheme of inverse wavelet transform

VI. RESULTS AND DISCUSSION

In this paper, we compared Discrete Wavelet Transform (HAAR & Biorthogonal Wavelet) &lifting scheme (LS) on DWT (HAAR & Biorthogonal wavelet). The coding of this paper is done in MATLAB 7.The quality of a compression method could be measured by the traditional distortion measures such as the peak signal to-noise ratio (PSNR), signal to noise ratio (SNR), Mean square error (MSE), Root mean square error(RMSE), execution time (ET), energy retained(ER). We compared the performance of these transforms on image “baby (64 x 64)”. Fig.7 shows the reconstructed images of HAAR & Biorthogonal Wavelet, and Lifting Transform on HAAR & Biorthogonal Wavelet.

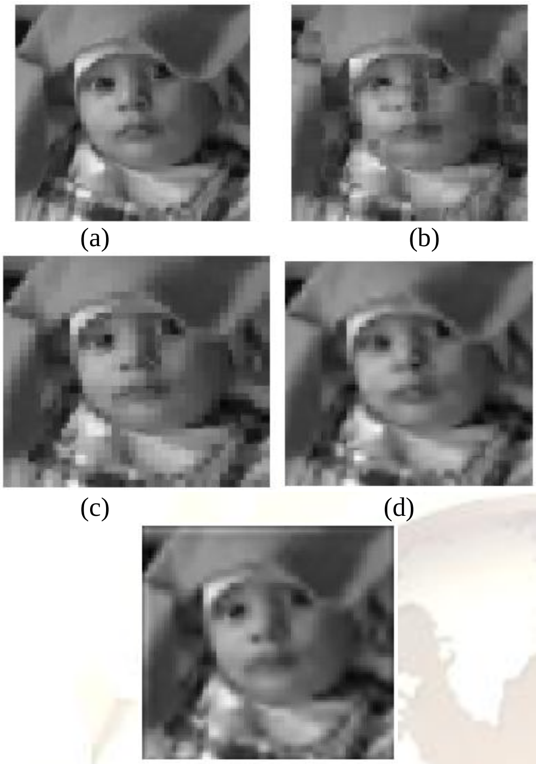

Figure7. (a) Original image ,(b) Compressed by HAAR, (c) Compressed by LS HAAR, (d) Compressed by BIOR, (e) Compressed by LS BIOR

Table 1: shows the various parameters for HAAR, BIOR, LSHAAR & LSBIOR

Transforms / Parameters	DWT		LWT	
	HAAR	BIOR	LSHAAR	LSBIOR
SNR(db)	33.0541	52.0700	36.5121	88.7595
MSE	0.0021	0.0014	0.0015	0.00007
RMSE	0.2766	0.2255	0.2364	0.1627
PSNR(db)	74.8691	76.6423	76.2344	79.4774
Execution Time(sec)	0.9048	0.6708	0.7488	0.4680
Energy Retained	98.8550	99.6768	99.9176	99.7534
Percentage of Zeroes	68.2617	71.6553	69.7621	72.7782

The bar graphs plotted on the basis of results described in Table 1. Fig.8 shows the improvement in SNR (db) for DWT (HAAR and BIOR) & LWT (LSHAAR and LSBIOR). It is clearly seen that Biorthogonal wavelet performs better than HAAR. After application of lifting transform on both HAAR and Biorthogonal wavelet, SNR is improved and lifting transform on BIOR (LSBIOR) gives best results. Figure 9 show Lifting Transform improves the execution time (in seconds).

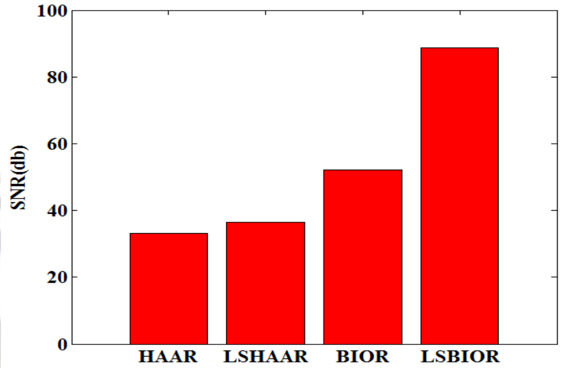

Figure8: Performance of Transforms in terms of SNR (db)

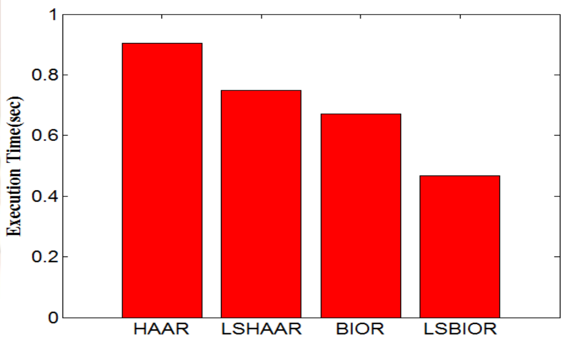

Figure9: Performance of Transforms in terms of Execution Time (sec)

Here are the two line graphs plotted on the basis of the variation of PSNR & MSE with threshold value. The increase in threshold value means increasing the percentage of zeroes and hence increases in quantization levels. Figure 10 concludes that with the change in threshold value PSNR (db) for BIOR is higher than HAAR wavelet & Lifting transform on both PSNR whereas lifting on BIOR improves PSNR. It can be clearly seen from figure 11 that for the same value of threshold mean square error (MSE) for BIOR and LSBIOR is quite less than HAAR and LSHAAR.

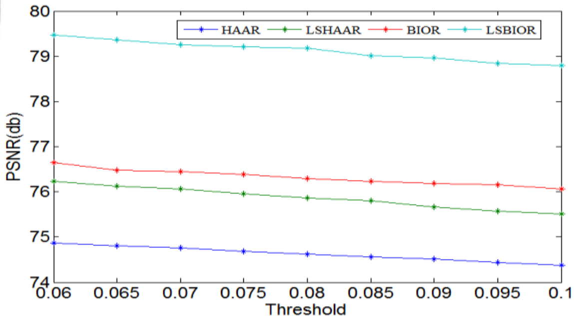

Figure10: Plot of PSNR (db) Vs threshold for HAAR, BIOR, and LSHAAR & LSBIOR.

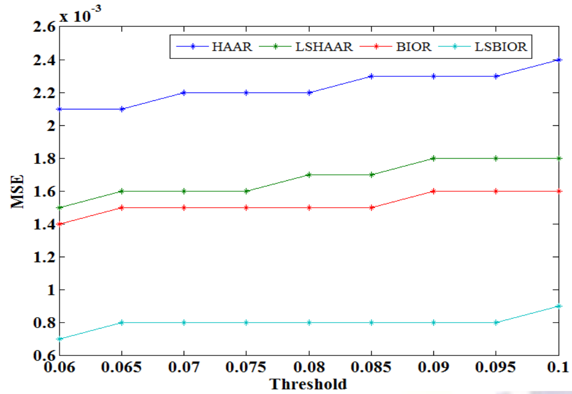

Figure11: Plot of MSE Vs threshold for HAAR, BIOR, and LSHAAR& LSBIOR.

VII. CONCLUSION

In this paper, we presented results from a comparative study of DWT & DWT with LS (lifting scheme) for image compression. DWT is implemented using two wavelets HARR & BIOR. BIOR proves to be better than HARR wavelet transform. Lifting scheme speed up the decomposition process with a comparable performance in peak signal to noise ratio (PSNR) and reconstructed image quality. BIOR gives best result with lifting scheme. This approach is suitable for the applications in which the speed is critical factor i.e. software based video conferencing and real time image compression systems.

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