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Image Denoising and Enhancement using Multilevel 2-D Dwt Lifting

Mahesh N. Javalkar, Gouri G. Uppin

Abstract- In general, images are often corrupted by noise in the procedures of image acquisition and transmission. The noise may seriously affect the performance of image processing techniques . Hence image denoising and enhancement plays an important role in the field of image processing. The Wavelet Transform provides a scale based decomposition . For discrete time signals , Discrete Wavelet Transform (DWT) is implemented by two methods , the convolution method and the lifting scheme method . The basic idea is done by filtering the input signal with a low pass filter and a high pass filter and downsampling the outputs by a factor 2 . The lifting scheme is an efficient method of wavelet transform and is far better than the convolution method because of its advantages like faster implementation of wavelet transform , requires lesser number of computations , allows fully in-place calculation and reversible integer wavelet transform. The lifting scheme can be applied forwardly to enhance or denoise the image and it can further be applied inversely to get back the original image. In this paper the 2-dimensinal lifting based discrete wavelet transform (2-D DWT) method is implemented for image denoising and enhancement . The 2-D DWT lifting scheme algorithm has been implemented using MATLAB program for both modules , Forward Discrete Wavelet Transform (FDWT) and Inverse Discrete Wavelet Transform (IDWT) to determine the Mean Square Error (MSE) and the Peak Signal to Noise Ratio (PSNR) for the retrieved image . To implement denoising different noisy images are taken and denoised using 2-D DWT lifting scheme. The results are compared in terms of MSE, PSNR and execution time values . To verify enhancement the proposed lifting based DWT method is compared with Histogram Equilization(HE) method. The results show much more improved contrast enhancement by lifting based DWT as compare to the HE method . The parameter comparisons like MSE (reduced to approximately 1/10th in lifting scheme as compare to HE method) , PSNR (almost doubled in Lifting scheme as compare to HE method) are obtained for different images to show better enhancement using lifting based DWT method .

Keywords- Histogram Equalization (HE), Discrete Wavelet Transform (DWT), Mean Square Error (MSE), Peal Signal to Noise Ratio (PSNR) , Lifting scheme Forward Discrete Wavelet Transform (FDWT, Inverse Discrete Wavelet Transform (IDWT)

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I. INTRODUCTION

Digital images play an important role both in day to-day applications, such as, satellite television, magnetic resonance imaging, computer tomography as well as in areas of research and technology such as geographical information systems and astronomy. In these diverse fields, scientists have faced with the problem of recovering original images from incomplete, indirect and noisy images. The objective of image enhancement is to improve the interpretability of the information present in images for human viewers. An enhancement process is one that gives a better quality image for the purpose of some particular application which can be done by either suppressing the noise or increasing the image contrast. Generally, data sets collected by image sensors are contaminated by noise. Imperfect instruments, problems with the data acquisition process, and interfering natural phenomena can all degrade the data of interest. There are many different cases of distortions. One of the most prevalent cases is distortion due to additive white Gaussian noise which can be caused by poor image acquisition or by transferring the image data in noisy communication channels. Other types of noises include impulse and speckle noises. Furthermore, noise can be introduced by transmission errors and compression. Thus, denoising is often a necessary and the first step to be taken before the image data is analyzed. It is necessary to apply an efficient denoising technique to compensate for such data corruption. Image denoising still remains a challenge for researchers because noise removal introduces artifacts and causes blurring of the images. Denoising of electronically distorted images is an old but also still a relevant industrial problem.

There are two basic approaches to image denoising, spatial filtering methods and transform domain filtering methods. Spatial filters employ a low pass filtering on groups of pixels with the assumption that the noise occupies the higher region of frequency spectrum. Spatial Low-pass filters will not only smooth away noise but also blur edges in signals and images while the high-pass filters can make edges even sharper and improve the spatial resolution but will also amplify the noisy background.

The spatial domain method operates directly on pixels where as the transform domain method operates on the Fourier transform of an image and then transforms it back to the spatial domain. Spatial domain technique deals with the manipulation of pixel values. Wavelet Analysis, a new form of signal analysis is far more efficient than Fourier analysis wherever a signal is dominated by transient behaviour or discontinuities.

Several investigations have been made into additive noise suppression in signals and images using wavelet transforms. The wavelet transform provides a scale-based decomposition. The wavelet transform of an image typicallyconsists of a large number of small coefficients (contain little information) and a small number of large coefficients (contains significant information). Thus each wavelet coefficient is probabilistically in two states: significant and insignificant. For discrete time signals, Discrete wavelet transform (DWT) is implemented by two methods , they are the convolution method and the lifting scheme method. The basic idea is done by filtering the input signal with a lowpass filter and a highpass filter and down sampling the outputs by a factor 2 . Applying the same decomposition to the low passchannel output yields a two-level wavelet transform; suchscheme can be iterated in a dyadic fashion to generate a multilevel decomposition. The lifting scheme is an efficient method of wavelet transform and is far better than the convolution method of wavelet transform. The lifting scheme can be applied forwardly to enhance or denoise the image and it can further be applied inversely to get back the original image.

The 2-dimensinal discrete wavelet transform lifting scheme algorithm has been implemented using MATLAB program for both modules forward discrete wavelet transform (FDWT) and inverse discrete wavelet transform (IDWT) to determine suitable word length for DWT coefficients and the peak signal to noise ratio (PSNR) for the retrieved image. Mean Square Error (MSE) and PSNR are used to do the computational analysis of the retrieved image with the original image.

II. HISTOGRAM EQUALIZATION TECHNIQUE (HE METHOD)

Histogram Equalization (HE) is a very popular technique for enhancing the contrast of an image It has proved to be a simple image contrast enhancement technique. However, it tends to change the mean brightness of the image to the middle level of the gray level range. A very popular technique for contrast enhancement of images is Histogram Equalization (HE). It is the most commonly used method due to its simplicity and comparatively better performance on almost all types of images. HE performs its operation by remapping the gray levels of the image based on the probability distribution of the input gray levels. It flattens and stretches the dynamics range of the image's histogram and resulting in overall contrast improvement. HE has been applied in various fields such as medical image processing and radar image processing. Nevertheless, HE is not commonly used in consumer electronics such as TV because it may significantly change the brightness of an input image and cause undesirable artifacts [17].

In Histogram equalization method based on the *RGB* color space for image enhancement we use *R*-red, *G*-green, and *B*-blue 1*D* histograms to estimate the histogram to be equalized using a Naive Bayes rule. The histogram equalization is performed by shift hue-preserving transformations. The method has linear time and space complexities, which complies with real time applications requirements.

Though this method preserves the input brightness on the output image with a significant contrast enhancement, they may produce image which do not look as natural as the input ones. The basic idea of HE method is to re-map the gray level of an image .HE tends to introduce some annoying artifacts and unnatural enhancement. Even though the HE algorithm is adaptive and efficient in image enhancement, it may generate undesired defects, like overly enhanced results, noise amplification and loss of fine detail.

One draw-back of the histogram equalization can be found on the fact that the brightness of an image can be changed after the histogram equalization, which is mainly due to the flattening property of the histogram equalization. Thus it is rarely utilized in consumer electronic products such as TV where preserving original input brightness may necessary in order not to introduce unnecessary visual deterioration. The drawbacks of HE method are as follows

(1) It does not have the mechanisms that adjust the degree of enhancement. It is also especially difficult to achieve a well-balanced enhancement effect over different parts of an image, e.g., the background and detail parts of the image.

(2) It often causes unpleasant visual artifacts, such as over enhancement, level saturation (clipping) and increase in the noise level.

(3) It could dramatically change the character of the image. For example, the average luminance of the image often becomes significantly different after the enhancement.

Because of the above shortcomings, histogram equalization is rarely used in practice in its original form. Variants of the HE method have been developed and in recent years, many improved HE-based enhancement techniques have been proposed

III. DISCRETE WAVELET TRANSFORM

The discrete wavelet transform (DWT) is obtained by filtering the signal through a series of digital filters at different scales. The scaling operation is done by changing the resolution of the signal by the process of subsampling. The DWT can be computed using either convolution-based or lifting-based procedure. In both methods, the input sequence is decomposed into low-pass and high-pass sub-bands , each consisting of half the number of samples in the original sequence. A Discrete Wavelet Transform (DWT) can be implemented through Filter bank or Lifting scheme

A. Filter Bank

Sub-band coding is a procedure in which the input signal is subdivided into several frequency bands. Sub-band coding can be implemented through a filter bank . A filter bank is a collection of filters having either a common input or common output. When the filters have a common input , they form an analysis bank and when they share a common output, they form a synthesis bank . The basic idea in a filter bank is to partition a signal dyadically at the frequency domain .

B. *Two-Channel Filter Bank*

The complete two-channel filter bank is composed of two sections Analysis section and Synthesis section . The analysis section decomposes the signal into a set of sub-band components and the synthesis section reconstructs the signal from its components. The sub-band analysis and synthesis filters should be designed to be alias-free and are also required to satisfy the perfect signal-reconstruction property. The simultaneous cancellation of aliasing as well as amplitude and phase distortions leads to perfect reconstruction filter banks which are suitable for hierarchical sub-band coding and multi-resolution signal decomposition. The analysis filter bank splits the signal into two equal frequency bands which are filtered and decimated. The synthesis filter bank reconstructs the signal from the two filtered and decimated signals.

C. *Sub-Band Coding of 2D Signal*

In the DWT an image signal can be analysed by passing it through an analysis filter bank followed by decimation operation. The analysis filter bank consists of a low-pass and high-pass filter at each decomposition stage. When the signal passes through these filters, it splits into two bands. The low-pass filter, which corresponds to an averaging operation, extracts the coarse information of the signal. The high-pass filter, which corresponds to a differencing operation, extracts the detail information of the signal. The output of the filtering operation is then decimated by two. A two-dimensional transform is accomplished by performing two separate one-dimensional transforms. First, the image is filtered along the row and decimated by two. It is then followed by filtering the sub-image along the column and decimated by two. This operation splits the image into subbands LL1,LH1,HL1 and HH1

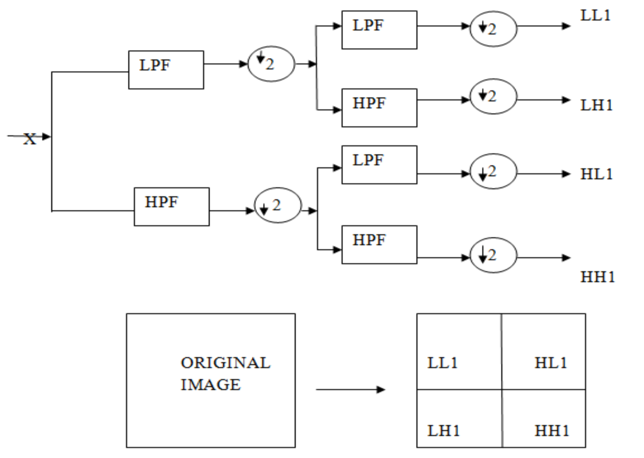

Figure1: First Level Wavelet Decomposition of Input Image

The figure shows the first level of decomposition (Separable System). Further decomposition can be achieved by acting upon the LL1 sub-band successively and the resultant image is split into multiple bands

D. *Lifting Scheme*

Lifting scheme can be used to compute the DWT. It is an efficient implementation of a wavelet transform algorithm. The lifting scheme entirely relies on the spatial domain, has many advantages compared to filter bank structure, such as lower area, power consumption and computational complexity. The lifting scheme can be easily implemented by hardware due to its significantly reduced computations. Lifting has other advantages, such as "in-place" computation of the DWT, integer-to-integer wavelet transforms which are useful for lossless coding. The lifting scheme has been developed as a flexible tool suitable for constructing the second generation wavelets. It is composed of three basic operation stages: split, predict and update. Fig.3.3 shows the lifting scheme of the wavelet filter computing one dimension signal. The three basic steps in Lifting based DWT are:

Split step: where the signal is split into even and odd points, because the maximum correlation between adjacent pixels can be utilized for the next predict step. For each pair of given input samples x(n) split into even x(2n) and odd coefficients x(2n+1) i.e,Xe=X(2n), Xo=X(2n+1)

Predict step: The even samples are multiplied by the predict factor and then the results are added to the odd samples to generate the detailed coefficients .Detailed coefficients results in high passfiltering.i.e, Y(2n+1) = Xo(2n+1) – P(Xe)

Update step: The detailed coefficients computed by the predict step are multiplied by the update factors and then the results are added to the even samples to get the coarse coefficients . The coarser coefficients gives low pass filtered output

i.e,Y(2n) = Y(2n+1) + U(Xe) Where, U is the new update operator.

The inverse transform could easily be found by exchanging the sign of the predict step and the update step and apply all operations in reverse order .The implementation of lifting based inverse transform (IDWT) is simple and it involves order of operations in DWT to be reversed. Hence the same resources can be reused to define a general programmable architecture for forward and inverse DWT.

Implementation and Simulation Image Denoising and Enhancement process

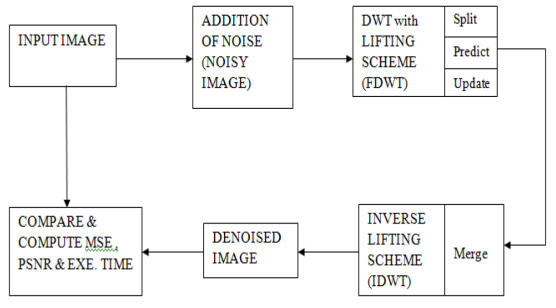

Figure2: Block diagram of Image Denoising and Enhancement technique

The above figure shows the block diagram of the proposed process. In the initial step an original image (like lotus , singletree) is fetched from memory and it is made noisy by adding one of the noise like Gaussian , Poisson , Salt and Pepper , Speckle , Blurred etc.

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This makes the original image an noisy image which is to be further denoised and enhanced by using the discrete wavelet transform with forward lifting scheme and inverse lifting scheme.

DWT with forward lifting scheme

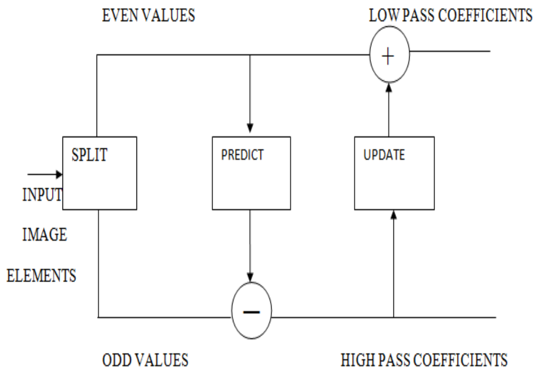

Figure3: Forward lifting scheme (FDWT) process

The lifting procedure consists of three phases , namely

1) Split Phase (Lazy Wavelet Transform)
2) Predict Phase (Dual Lifting)
3) Update Phase (Primal Lifting)

1. Split Phase

The first phase in the lifting scheme is to separate the original sequence into two sub-sequences containing the odd-indexed samples and the even indexed samples .Each group consists of one half samples of the original signal .This sub-sampling step is also called the Lazy Wavelet Transform because it is splitting the signal in two parts and no mathematical operation is performed. If we remove any of the frames the signal information will be lost. For each pair of given input samples x(n) split into even x(2n) and odd coefficients x(2n+1) i.e,Xe=X(2n) and Xo=X(2n+1) . The Split Phase code is simulated using Matlab.

2. Predict Phase

In the prediction step which is also called dual lifting , the odd samples are predicted using the neighbouring even indexed samples and the prediction error (detail) is recorded replacing the original sample value , thus providing in-place calculations. The even samples are multiplied by the predict factor and then the results are added to the odd samples to generate the detailed coefficients .Detailed coefficients results in highpassfiltering.i.e, Y (2n+1) = Xo(2n+1) – P(Xe) . The Predict Phase code is simulated using Matlab.

3. Update Phase

The detailed coefficients computed by the predict step are multiplied by the update factors and then the results are added to the even samples to get the coarse coefficients The coarser coefficients gives low pass filtered output i.e,Y(2n) = Y(2n+1) + U(Xe) , Where, U is the new update operator. The Update Phase code is simulated using Matlab.

DWT with Inverse Lifting Scheme

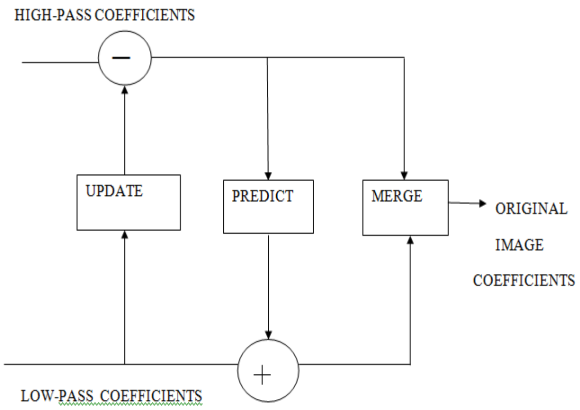

Figure4: Inverse Lifting Scheme (IDWT) process

The Inverse lifting scheme can be implemented by the following steps

a. Undo Update (Inverse Primal Lifting):- Original even samples are recovered by subtracting the update information.

b. Undo Predict (Inverse Dual Lifting):- Odd samples can be recovered by adding prediction information to loss of Information.

c. Merge: - After recovering odd and even samples, final job is to merge them together to obtain prior signal. To compress the signal, even samples are scaled by inserting zero values in between the samples and then odd samples are placed in place of zeros.

The inverse transform is obtained by exchanging the sign of the predict step and the update step . All the operations are applied in reverse order as compare to the forward lifting scheme. Lastly both the outputs i.e, from predict stage and the update stage are merged to get the original image coefficients. The Inverse Lifting code is simulated using Matlab.

IV. DENOISED IMAGE

The application of the inverse lifting scheme does the reconstruction of the original image i.e, which removes the noise from the image and enhances the noisy image to the original image which is called the denoised image.

Computation of MSE, PSNR

PSNR means peak signal-to-noise ratiowhich is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of the logarithmic decibel scale. The PSNR is most commonly used as a measure of quality of reconstruction of noisy image. The signal in this case is the original data, and the noise is the error. A higher PSNR would normally indicate that the reconstruction is of higher quality. It is most easily defined via the mean squared error (MSE) which for two m×nmonochrome images *I* and *K* where one of the images is considered a noisy approximation of the other is defined as:

$$MSE = 1/mn \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i,j) - K(i,j)]^2$$

The PSNR is defined as

$$PSNR = 10.\ \log_{10} (MAX_I^2/MSE)$$
$$= 20.\ \log_{10} (MAX_I/\sqrt{MSE})$$

Here, MAX_I is the maximum possible pixel value of the image. When the pixels are represented using 8 bits per sample, this is 255. More generally, when samples are represented using linear PCM with B bits per sample, MAX_I is 2B−1. For color images with three RGB values per pixel, the definition of PSNR is the same except the MSE is the sum over all squared value differences divided by image size and by three. The computation of MSE and PSNR is done by using Matlab code.

Result

	Lifting			Histogram Equalization		
	MSE	PSNR	Time	MSE	PSNR	Time
Lotus.tif	0.00380	24.01969	312.5	0.079	11.0035	93.75
Pepper.tif	0.0247	16.07	312.5	0.034	14.59	78.125
Singletree.tif	0.0055	22.53	265	0.039	13.99	93.75
Bike1.tif	0.007	21.3133	250	0.061	12.1108	109.375

Table 1: Shows the comparison of Lifting and HE enhancement methods

	Bike1.tif		Lotus.tif		Pepper.tif		Singletree.tif	
	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR
No noise	0.00730	21.3133	0.00380	24.1969	0.0247	16.07	0.0055	22.53
Gaussian	0.01184	19.2637	0.00833	20.7904	0.0245	16.1006	0.00795	20.996
Poisson	0.00789	21.0257	0.00412	23.8419	0.0242	16.161	0.00550	22.589
Salt & pepper	0.00812	20.902	0.00468	23.2948	0.0246	16.759	0.00597	22.2365
Speckle	0.01026	19.888	0.00573	22.4161	0.0208	16.812	0.00651	21.861
Blurred	0.01554	18.082	0.0105	19.7559	0.0297	15.2588	0.00867	20.6172

Table 2: Shows the Denosing Analysis

The Lifting based DWT technique gives better simulation results for image enhancement. The simulation result shows that with higher value of PSNR gives better visual quality and it is summarized in Table 1 over different images. We can find that Lifting based DWT method produces lower value of MSE and higher value of PSNR in all cases as compared with HE algorithm. It is also interesting to compare the simulation result of Lifting based DWT and HE technique in terms of execution time. The table 1 summarizes the MSE , PSNR and execution time for Lifting based DWT as compared with HE algorithm. The simulation results also show denoising using Lifting based DWT for various images and the results are compared in terms of MSE , PSNR and execution time values . The table 2 summarizes the MSE , PSNR values for various images. Here it represents that the Lifting based DWT method gives better improvement in image enhancement than HE method (ie MSE is reduced to approximately $1/10^{th}$ in Lifting method as compare to the HE method and PSNR is almost doubled in many cases). HE and Lifting based DWT methods are implemented using Matlab on Laptop with Intel Core i5 2.93 GHz CPU. As expected the proposed Lifting based DWT gives better result including the PSNR and MSE values.

V. CONCLUSION

In this project, the Multilevel 2D Lifting based DWT for image denoising and image enhancement is proposed. Unlike the various approaches, the proposed method considers the issues that influence the visual quality of the captured image as well as the statistical properties of natural images .The performance parameters like MSE, PSNR indicate the superiority of the proposed technique. Simulation results of the proposed method verify the feasibility of the proposed algorithm in the task of image denosing and enhancement. The simulation results show the effectiveness of the algorithm in comparison to HE enhancement algorithm. Obtained images are visually pleasing, artifact free, and natural looking. A desirable feature of the proposed algorithm is that it is effectively used for denoising which is crucial for image processing applications. The proposed method is applicable to a wide variety of images . It also offers a level of controllability and adaptivity through which different levels of image enhancement takes place. As the outcome demonstrated, Lifting based DWT outperforms other methods like Histogram Equalization in terms of MSE and PSNR values.

This method of multilevel 2-D Lifting based DWT can be used for new methods of pipelined architechtures capable of handling multiple data streams suitable for applications in image and video processing multimedia real time applications.

We can also implement VLSI architecture for efficient hardware implementation of 2-D DWT lifting scheme which can be analysed in terms of hardware and timing complexity for the given size of input image and required levels of decomposition. This concept is useful in deriving an efficient method for improving the speed and hardware complexities of existing architectures.

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