Wavelet Based Image Analysis:A Comprehensive Survey

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Abstract*— Wavelet theory is one the greatest achievement of last decade. Wavelet theory has gained popularity in solving difficult problems in mathematics, engineering etc. It can be employed in lots of fields and applications, such as signal processing, image analysis, communication systems, time frequency analysis, image compression, smoothing and image denoising , pattern recognition, finger print verification, DNA analysis, computer graphics etc. The results produced by wavelet based analysis have really astonished the modern research communities in various fields. Wavelet based analysis is still an active research area due to its tremendous applications. This paper provides basic concepts of wavelet transforms and brief idea of recent published works dealing with applications of wavelet theories.

***Keywords*— Dual Tree Complex Wavelet, Image compression, Image denoise, Multiresolution analysis, Zero crossing.**

I. INTRODUCTION

Wavelet transform is a mathematical technique that decomposes the signal into series of small basis function called wavelets. It allows the multiresolution analysis of image and is well localized in both time and frequency domain. As a result of wavelet transform the image is decomposed into low frequency and high frequency components. The information content of these sub images that corresponds to Horizontal, Vertical and Diagonal directions implies unique feature of an image. Multiresolution analysis can be performed by passing the original image first through the low-pass and high-pass decomposition filters to generate four lower resolution components are shown in fig1: one low-low (LL1) sub-image, which is the approximation of the original image and three detailed sub-images, which represent the horizontal(LH1), vertical(HL1) and diagonal directions(HH1) of the original image. The sub-band LL1 alone is further decomposed to obtain (LL2, LH2, HL2 and HH2) the next coarse level of discrete wavelet coefficients; similarly, further decomposition of LL2 is done to obtain the next coarse level. This decomposition process continues until some fine scale is reached.

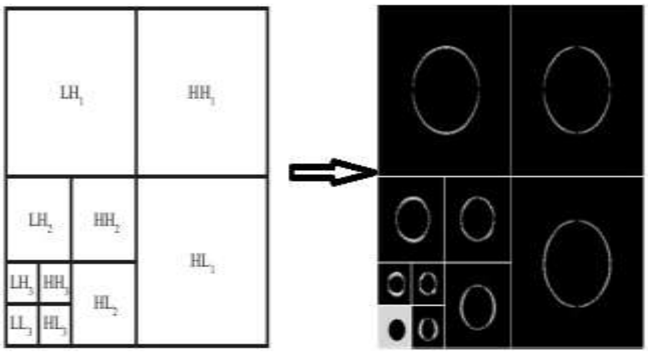

Fig 1: Multiresolution analysis of image

Like humans, wavelets also live in families. Each member of a family has certain common features that distinguish each member of a family. Some wavelets are for continuous wavelet transform and others are for discrete wavelet transform. It does not have single set of basis function like Fourier transform, it have infinite set of basis functions. Based on these basis function wavelets are classified as Haar, Coiflet, Daubechies, Symlet, Biorthogonal etc. The Haar wavelet is the only wavelet that is compactly supported, orthogonal and symmetric. The family of symlet wavelet is short of symmetrical wavelets but they are not perfectly symmetrical. Ingrid Daubechies invented compactly supported orthonormal wavelets; this becomes the one of the brightest stars in the world of wavelet research, thus making discrete wavelet analysis practicable. Coiflets wavelets are similar to daubechies wavelet they have a maximum number of vanishing moments and are nearly symmetric.

Wavelet Transform is more efficient than Fourier transform which faces the resolution problem and localized in frequency domain only. At the beginning of the 20th century [1], Haar, a German mathematician introduced the first wavelet transform named after Mallat. Then various new theories started to develop based on wavelet concept, which has been widely applied in different fields. Result of the tremendous researches conducted by Mallat, Meyer and Daubechies, turned out to be the greatest achievements in the field of signal processing. They frame worked the emergence of a wide range of wavelet based application. Few years later, set of biorthogonal basis functions were developed which led to the development of different wavelet basis for image processing applications. This paper is arranged to focus on recent applications in the field of wavelet theory.

II. LITERATURE REVIEW

A number of researches have been proposed over the years for wavelet based analysis. Nowadays, the wavelet transform is being increasingly used, not only in the field of image and signal processing application but also in many other different areas, ranging from mathematics, physics and astronomy to statistics. In image processing based applications, image compression, image denoising, image fusion, iris recognition, character recognition, texture classification and as such , brief description of these wavelet based applications is given in this section.

A. Image Compression

Image compression can be achieved by removing redundancy and irrelevancy from image data in order to be able to store and transmit data in an efficient form and it plays a very important role in the field of multimedia application. Depending on the application; image compression can be lossy or lossless. In lossy compression the image size would be highly reduced but on reconstruction does not produce the original image. In lossless compression, every single bit of data that was originally in the file remains after the file is uncompressed. The images can be decomposed into four parts by two dimensional wavelet transform. The decomposition can continue to scale level as specified by the user. By avoiding some detail part of image and keeping only the approximation part high compression in images can be encountered.

Mozammel Hoque et.al [2] propose a new compression scheme based on discrete wavelet transformation (DWT) and it results less computational complexity with no degradation in image quality. The proposed technique decomposes an image in to sub-bands and then resulting coefficients are compared with a threshold. Coefficients below the threshold are set to zero and above are encoded with loss less compression techniques. In this paper, the author compared the proposed algorithm with some other common compression standards for performance analysis. From this comparison, Wavelet is better suited to time limited data and it maintains better image quality with high compression ratio.

The image consists of pixels that are arranged in to two dimensional matrix, each pixel represents the image intensity. For compress the images, these redundancies existing among the pixels needs to be eliminated. In this case, Dipalee Gupta et.al [3] uses discrete wavelet like haar and daubechies wavelets for comparing the performance of still image compression system. The quality of compression method could be measured by using some measuring qualities like mean square error and energy retained. From this comparison daubechies wavelet transform shows the best result as compare to haar wavelet transform. A brief study of various wavelet families and compression techniques described in [4] by meenakshi chaudhary et.al. From their study, Compression is necessary in digital image processing. Wavelets are suitable method for compression of biomedical images because they provide exceptional image quality at high compression rate and mean squared error (MSE) is minimized and peak signal to noise ratio (PSNR) is maximized.

B. Image Denoising

Image denoising involves the manipulation of the image data to produce a visually high quality image. Wavelets give a vital role in image denoising because it has good local time-frequency, multi-scale and multi-resolution characteristics. These characteristics are very useful for locating particular features of interest in an image. Simple denoising algorithms that use discrete wavelet transform followed by a threshold operation. This method exploits the energy compaction ability of the wavelet transform to separate the image from the added noise. The role of threshold is to eliminate the noise present in the image. Finally, enhanced denoised image is recovered by applying the inverse discrete Wavelet transform.

Gagandeep kour et.al [5] has presented a denoising algorithm where daubechies wavelet decomposition technique is applied to filter the input image for enhancing the quality. A specific threshold value is determined to decompose the original image. Finally, filter is applied for image enhancement. De-noising methods based on wavelet decomposition is one of the most significant applications of wavelets. Here, the threshold plays an important role in the de-noising process. Soft thresholding and hard thresholding are frequently used thresholding methods. Finding an optimum threshold is a difficult process. A small threshold value will retain the noisy coefficients whereas a large threshold value leads to the loss of coefficients that carry image details. This proposed experiment shows good denoising method while calculating PSNR and MSE.

In [6] Vinita Arun chaudhari et.al, reviewed different image denoising techniques using wavelet transform. From their study, denoising of natural images corrupted by Gaussian noise using wavelet techniques is very effective because of its ability to capture the energy of a signal in few energy transform values and they allow analysis of images at various levels of resolution. The wavelet based denoising methods preserved sharpness of the images from the original shapes of active regions as well and produced a smaller total number of errors than Gaussian noise. The Wavelet outperform better than Gaussian giving maximum output of above 10db at high signal to noise ratio (SNR). But the problem is, Gaussian and wavelet based smoothing methods introduced severe deformations and blurred the edges of the images. According to their review, they proposed a new denoising technique named wavelet decomposition method with filtration method. In this method, noise is added with original image after that the wavelet decomposition is used and applies proposed filtration method for better results.

C. Image Fusion

Image fusion is the process of extracting meaningful visual information from two or more images and combining them to form one fused image. Discrete Wavelet Transform has a wide range of application in fusion of noisy images and effective fusions of images aim to retain important features from all input images. But this transform suffers from the shift variance and lack of directionality associated with its wavelet bases. For overcome this problem dual tree complex wavelet transform is used for image fusion.

In [7], souparnika jadhav propose image fusion algorithm based on dual tree complex wavelet transform (DTCWT). Dual tree CWT is an extension to discrete wavelet transform and is able to retain edge information without ringing artifacts. It is also good at retaining textures from input images. The motivation for using the DTCWT for image fusion is its shift invariance property together with its improved directional selectivity. In this paper, decompose each input image into sub-images using complex wavelet transform and then the information fusion is performed using high frequency sub- images under the gradient approach and resulting image is obtained using inverse dual tree wavelet transform.

Rudra pratap singh et.al [8] proposes dual tree-complex wavelet transform based image fusion method and it gives best results than the discrete wavelet transform based techniques. DT-CWT improves the directional selectivity which is the prime concern in the application like image fusion. Due to improved directive and shift invariant properties of DT-CWT fusion method outperforms the DWT fusion method. In all wavelet based image fusion, the wavelet transforms of the two input images are computed and these transforms are combined using some kind of fusion rule. Since wavelet coefficients having large absolute values contain the information about the salient feature of the images such as edges and lines. Then, the inverse wavelet transform is computed and the fused image is reconstructed. Image fusion plays an imperative role in various real life applications such as medical image diagnosis and remote sensing. Because of acquired images are corrupted from various noises hence fusion of image is an integrated approach where reduction of noise and retaining the original features of image is essential.

D. Iris Recognition

Iris recognition is a reliable technique for human identification. Examples include computer login control, passport control, bank automatic teller machines and other transactions authorization. Feature extraction is an important step for iris recognition and extracted features are used for matching. Different wavelet transforms have been used by different researchers for feature extraction in iris recognition.

Sandipan P Narote et.al [9] proposes iris based recognition system using wavelet transform. In this paper, different mother wavelet such as haar, daubechies, coiflet, symlet and biorthogonal are used for feature extraction and their performance is evaluated for determine the optimal wavelet transform. The iris recognition system consists of iris acquisition, preprocessing, feature extraction and feature comparison. In iris acquisition systems, the iris image with a smaller pixel (200 pixels) is considered as being a better quality image and a bigger pixel as being a lesser quality image. In this work, decompose the normalized image using fifth level decomposition. The result obtained from the feature vectors of different combinations (HH5, HL5 and LH5) are compared to find the best. The last module of an iris recognition system is used for matching two iris templates. Its purpose is to measure how similar/different templates are and to decide whether they belong to the same individual or not. The test of matching is implemented by using Boolean Exclusive-OR operator (XOR). This algorithm performs matching of two templates several times while shifting one of them to four different locations. The smallest Hamming distance value is selected, which gives the matching. From his proposed work, db9 wavelet gives an accuracy of 99.98%.

E. Character Recognition

Character Recognition (CR) is one of the most successful applications in the areas of pattern recognition and artificial intelligence. It is the process of detecting and recognizing characters from input image and converts it into machine recognizable form. Handwritten Character Recognition (HCR) is useful in cheque processing in banks, almost all kind of form processing systems, handwritten postal address resolution and many more. One of the main advantages of the CR process is that it can save both time and effort when developing a digital replica of the document. CR process can be classified in to two categories namely Off-line CR and On-line CR. The study investigates that in any character recognition system there exist three major stages such as Preprocessing, Feature Extraction and Classification. Feature extraction stage for extracting multiresolution feature of character image with wavelet. The details of character image at different resolutions generally characterize different physical structure of the character, coefficient obtained from wavelet transform can be very useful in recognizing character image.

B. V. Dhandra et al [10] developed an algorithm for extracting features from Kannada characters. In this algorithm, two level forward wavelet packet transform is applied to the character image using db4 filter. Here sub images corresponding to three directions, horizontal, vertical and diagonal. The information content of smooth component and high pass filtered components in the three directions should unique feature of image. These features are the number of zero crossing of wavelet coefficient in sub image. Then count the number of zero crossings, the position of sharp variation points in an image, out of the resulting sub bands and this number is taken as a feature vector. The KNN classifier is applied for classification of vowels and to get the average recognition accuracy of the proposed algorithm is 95.07%. By using this concept of zero crossings of discrete dyadic wavelet transform, Xian Zhao et al [11] have recognized character in scanning map and it is considered as the primary investigation in this field.

George S Kapogiannopoulous et al [12] applied biorthogonal discrete wavelet transform to decompose the curvature function which characterizes the contour of the handwritten character image. Wavelet representation of curvature function has the advantages that variations in the shape of the curve will cause only minor changes in the wavelet representation and this method achieves great recognition accuracy of 97%.

Suzete E. N. Correia et al [13] used Cohen- Daubechies- Feauveau (CDF) family of bi-orthogonal spline wavelets as feature extractor for absorbing local variations in handwritten characters and a multilayer cluster neural network as classifier. From his study, finds that the recognition rate of 94.7% obtained with CDF 3/7 is superior to that of Haar wavelet. The Cohen- Daubechies- Feauveau (CDF) family of bi- orthogonal spline wavelets has special properties such as short support and regularity which is useful for off-line recognition of unconstrained handwritten numerals.

F. Texture Classification

Textures are the important characteristic for the analysis of different types of images. The different regions of an image are identified based on its textural characteristics by using texture classification techniques and it assign the given texture region to one of the known set of the texture classes.

Texture analysis is a one of the challenging area of research because of its difficulty to analyze a both natural and artificial textures using single method. The texture analysis methods are classified into structural, statistical, model based and signal processing methods. But in all these methods, textures are analyzed on a single scale. For avoid this limitation, multiresolution analysis method is used. Here, Punamchand M Mahajan et.al [14] proposed a method to identify appropriate wavelet basis function using multiresolution approach based on pyramidal wavelet transform for classification of the textures in various classes. Dyadic wavelet decomposition of every input texture image achieved using various wavelet basis functions such as haar, daubechies, symlet, coiflet, biorthogonal and reverse biorthogonal wavelet for characterizing texture images at multiple scales. Each texture image is decomposed into various sub-bands with three level wavelet decomposition. Finally, classification efficiency is tested using minimum distance classifier along with various wavelet basis functions. From their proposed work, identify that haar wavelet as the best wavelet basis functions for texture classification. Marcin Kociolek et.al [15] use discrete wavelet transforms derived features used for image texture analysis. Wavelets are effective for analysis of textures recorded with different resolution and it is very important in NMR imaging. This proposed work provides a tool for fast, low resolution NMR medical diagnostic.

Analysis between various wavelet based techniques that is mentioned in this section is summarized in the following table1.

Paper	**Application**	**Wavelet Used**	**Result**
Mozammel Hoque Chowdhury et.al[2]	Image Compression	Morlet Daubechies	Compression Ratio: 24.22:1
Dipalee Gupta et.al[3]	Image Compression	Haar Daubechies	98.03%
Gagandeep Kour et.al[5]	Image Denoising	Daubechies	84.78% MSE: 0.3632
Vinita Arun Chaudhari et.al[6]	Image Denoising	DWT	High SNR

Souparnika Jadhav et.al[7]	Image Fusion	DTCWT	High SNR
Rudra Pratap Singh Chauhan et.al[8]	Image Fusion	DTCWT	High SNR
Rudra Pratap Singh Chauhan et.al[16]	Image Fusion	DTCWT	High PSNR
Sandipan P Narote et.al[9]	Iris Recognition	Haar Daubechies Symlet	db9
B.V. Dhandra et.al[10]	Character Recognition	db4	95.07%
George S Kapogiannopoulos et.al[12]	Character Recognition	Biorthogonal wavelet	95.62%
Joohyun Lim et.al[17]	Character Recognition	Gabor Haar Daubechies	Gabor
Suzete E. N. Correia et.al[13]	Character Recognition	CDF 2/2 CDF 2/4 CDF 3/3 CDF 3/7	CDF 3/7 94.7%
Punamchand M. Mahajan et.al[14]	Texture Classification	Haar	91.66%
Marcin Kociolek et.al[15]	Texture Classification	DWT	DWT

Table I: Analysis of various Wavelets based Techniques

III. CONCLUSION

Since the late 80's, the wavelet transform has been widely used in different scientific applications including signal and image processing. This enduring emergent success, which has been characterised by the adoption of some wavelet based proposal, is due to features inherent to the transform, such as multiresolution capabilities and time-scale localisation. The ultimate intent of this paper was to present the basic concept of the wavelet transform from a viewpoint that targets image analysis applications such as data compression, image denoise, image fusion, character recognition, iris recognition and texture classification. Different types of algorithms have been developed for image compression over the years. Among them, the discrete wavelet based compression technique gives better performance compared to other traditional techniques. It provides good quality reconstructed images at high compression ratio and reduces the blocking artifacts that are common in other compression techniques. The wavelet based noise removal techniques based on abandoning the information not needed proved very effective in controlling the image in the way you want. The texture analysis, character recognition and iris recognition are quite interesting but considered as difficult problems in image processing and wavelet based analysis facilitate to provide appropriate solutions. The popularity of wavelet transform is increasing day by day as it provides effective computational advantages over other methods. Identifying the suitable wavelet that has to be used in an application is still a vigorous problem in the research world today.

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