1 INTRODUCTION

1.1 Background

Large amount of data needs to be processed and stored in various application areas such as medical imaging, satellite image processing, pattern recognition, data matching etc. there is also increasing demand for transmission of these data across computer networks. In spite of rapid development in storage and transmission technology, compression of data is required because of huge data base requirement in above-mentioned applications.

Small 1024 x 1024 satellite image needs 1024 x 1024 x 24 bits or 3 megabytes memory; to store such even 1000 images 3Gb storage space is required. To transmit one image over 1mb/s channel we need 24 seconds. Thus to reduce storage space as well as transmission time, image compression is required.

Extensive research has been done in the field of image compression. Image compression techniques can be classified lossy and lossless. Lossless compression is fully reversible with no loss of information but limited compression is achieved. Lossy compression is irreversible and loses information. However quite high compression ratios can be achieved. All compression techniques try to remove data redundancies to achieve data compression. But they can be divided into two classes transform domain techniques in which data is transformed using DCT, DTWT, and FFT etc. and then transformed data is encoded. Non-transform techniques compression is achieved in spatial domain using PCM, DPCM etc it is also possible to combine both techniques.

For compression purpose, compression standard is defined as JPEG. From baseline JPEG standard is updated in due course of time to JPEG 2000. It is latest compression standard for lossy as well as lossless techniques. Baseline JPEG uses DCT transformed data. While JPEG 2000 uses wavelet transform. This change is incorporated due to many useful properties of wavelet transform.

1. In DCT based compression, first image is partitioned into blocks and then DCT coefficients are formed. This step is necessary to reduce number of
computations. But at the same time this gives blocking artifacts. In wavelet based coding, no partition of the image is required. This avoids blocking artifacts and gives better quality at intermediate and high compression ratios.

2. Fast image inspection of large volumes of images transmitted over low bandwidth channels like ISDN, public switched telephones or satellite N/W requires compression schemes with progressive transmission capabilities. The ability of wavelet based compression technique to create embedded data stream feasibilities the progressive transmission of data over N/W with limited bandwidth. In this method coarse version of the image corresponding to a certain refinement level is transmitted first. After decoding image is displayed at the remote site. If user is interested then image is refined up to lossless image. This is known as quality scalability. If user is not interested in entire image only part of interest of the image can be refined such region of interest coding or ROI coding is also possible due to wavelet transform properties.

Due to above mentioned requirement, which can be easily fulfilled by wavelet transform, it is the suitable choice of state of the art compression techniques.

1.2 Literature review

Wavelet transform finds its origin in the work of Gosman and Morlet since 1984. Theory of wavelet transform is well explained in [1] [2] [3] [4]. Mathematical properties of wavelet transform useful for compression are discussed in [5]. Detail analysis of transform coding is given in [7].

Wavelet transform is realized using QMF filter. Characteristics of such filters such as symmetry, regularity, order is explained in [10]. Performance analysis of filters from different families is done by [8][9][10][11]

Compression schemes in transform domain uses quantization after converting signal into Wavelet transform. Scalar quantization is old technique of quantization. It has been used successfully for one-dimensional as well two-dimensional data. Detail explanation
of quantization is given in [12][13][14]. Quantization is the process, which decides compression ratio. Rate distortion theory [15] says that for higher compression or lower bit rate more distortion results, and vice versa. Theory of various types of quantizers such as uniform and nonuniform quantizers is also explained in [12][13][14].

In JPEG, DCT coefficients are scalar quantized using quantization tables. Quality of reconstructed image is decided by quantization table used.

To understand, how properties of wavelet transform coefficients differ compared to spatial domain properties comparative study is required.

Compression schemes, which use Wavelet transform, also make use of scalar quantization to achieve required rate. For multispectral data, medical images, and also for fingerprint images it can give good compression.

Scalar quantization is included in the standard for fingerprint compression [16]. Quantization tables are used for quantization, which are image specific. Quantization levels are decided using bit allocation scheme, which minimizes distortion. Bit allocation is based on variance of subbands. In JPEG 2000 part –I standard wavelet coefficients of image are scalar quantized at the rate decided rate by user. [17]

As wavelet transform gives space frequency decomposition, instead of single quantizer, we can use separate quantizer for different frequency bands and different orientations.

To decide number of levels of these quantizers bit allocation schemes are suggested by Jayant [13]. In [18] number of bits or quantization levels are assigned based on variance of the source. Optimum Bit allocation based on Langrange cost function is used in [19].

Based on Langrange cost function search routine is given in [19]. While some different approach is taken by Gersho [20]. He has given bit allocation procedure based on activity in image. Though technique is explained for spatial domain. Same can be extended for transform domain.

Wavelet packet based space frequency quantization scheme is presented in [21]. All these schemes use uniform quantizers. Entropy constrained scalar quantizers are tried by [22][23]. However clear comparison of single quantizer scheme for all bands and separate quantizer for each band is not found. Non-uniform quantizer using Lloyd max algorithm in wavelet domain is also not tried.

In place of fixed quantizers, adaptive quantizers are used by few authors. Adaptive quantizer scheme implemented by Joshi and Crump [24] classifies transform
coefficients into different classes using blockwise classification. For every class separate quantizer exists. However this needs side information about the class. Reducing size of the block gives better classification results but increases overhead cost further.

Context based adaptive classification technique is implemented by Yoo and Yu [25]. Classification of current transform coefficient is done, considering previous quantized coefficients. Classified coefficients are assumed to have Laplacian distribution. Then quantizer is designed for each class with the help of model parameter. Bit allocation scheme is also employed.

Ortega in [26] has used fixed uniform quantizer for all subbands. Quantized coefficients are classified based on past neighboring coefficients (contexts). Predictor calculates magnitude of context template, based on the magnitude current pixel is classified into different classes. Classified coefficients are encoded using arithmetic coder with probability model of each class.

For context based arithmetic coding, context selection and prediction are the important components. Important class of predictor is linear predictor. In linear predictor contribution of every neighboring pixel that belongs to the context template is summed with weights to produce the prediction. Static linear predictors have constant weights to give prediction. In JPEG-LS [27] such 7 predictors are used. These predictors are simple but not efficient in terms of entropy reduction. Predictors, which have weights, that are varied for each prediction event based on local neighborhood is adaptive predictors. Graham predictor [28] MED [29] and GAP [30] are these types of predictors.

Graham switching predictor uses two separate predictors for vertical edge and horizontal edge. This predictor uses causal template of three surrounding pixels. GAP (gradient adjusted predictor) is used in CALIC (context adaptive lossless image codec). It uses causal template of seven surrounding pixels. First, gradient value is detected and then selects one of the seven static linear sub predictors. MED predictor (median edge detection) is a nonlinear predictor. It is used in LOCO-I. After detecting edge direction it uses non-linear prediction rules such as minimum, maximum. Extended CALIC [31]
by Wu uses inter-band correlation for multiband images compared to only intraband correlation used in CALIC. [32] Weinberger and Rissanen have used linear predictor for spatial domain image. Predictor weights are decided by linear regression.

In all above-mentioned methods from [24] to [32] prediction errors in given context are encoded using arithmetic coding. Arithmetic coding can achieve bit rate equal to zero order entropy of the source [35]. However using context based arithmetic coding entropy lower than zero order entropy can be obtained for this probability distribution of every context is required to know. To get exact probability distribution we have to use two pass method. To encode the image in one pass, instead of exact distribution probability models are used. Laplacian, Gamma or mixed distribution models are used by authors. For every context we need to specify model parameters. Universal context modeling is given by [32]. This method improves result by 0.42 bits for Barbara image for lossless compression, but the method is complicated.

Increasing number of pixels or coefficients in contexts template gives efficient entropy reduction but this increases number of contexts and model cost. To reduce model cost context quantization is used. Context quantization reduces model cost but increases entropy (compared to no quantization). By applying properly designed context quantizer better compression performance can be achieved. Optimal context quantizer is found by Chen [33] using Lloyd style algorithm from training images optimum quantizer is obtained. Clustering of context used by Lehtinen and Kivijarvi [34] also reduces the cost of model.

It is clear from above discussions that due to context-based entropy coding compression ratio can be increased with the use of efficient predictor and correct probability model. However most of the experimentation reported above is in spatial domain or in multispectral domain. Efficient adaptive Linear predictors such as MED, GAP are well tried in spatial domain but their performance is not evaluated in wavelet domain. Nonlinear predictors such as median, 'max' are also not tested in wavelet domain. There is scope for designing context predictor in wavelet domain. Also simple context quantization or context classification techniques can be explored which can exploit wavelet properties.

Quantization efficiency can be improved by using vector quantization instead of scalar quantization. Vector quantization is a technique in which group of pixels or transform
coefficients are quantized by single quantization index. Theory of vector quantization is explained by Gersho in [36]. Subband based VQ techniques have been implemented by various authors [37]. In spatial domain adjacent pixels are grouped to form N dimensional vector. For uniform subband or wavelet VQ, wavelet coefficients are grouped either from same band i.e. intra-band or inter-band. Same orientation cross band or same level cross band vector method is tried by different authors. Westerink, Boekee [38] used 21 dimensional same orientation vectors from three level decomposed images. Here one coefficient from lowest frequency band 2X 2 or 4 coefficient from next higher band and 4X 4 coefficients from highest band were selected. In this scheme vector size increases very rapidly. i.e. if we use four level decomposition of image, vector size will grow to 85. This increases compression ratio at the cost of quality.

[39] Has formed vectors by using same level coefficients. Coefficients from all orientations of level 3; LH3, HL3 and HH3. Then LH2,HL2,HH2 etc. ‘Same orientation all levels’ or ‘same level all orientation’ cross band method does not include lowest frequency band coefficient. This is because low frequency band has very different characteristics both perceptually and statistically compared to other bands. Intra-band vector formation is also possible. i.e. spatial adjacent coefficients from same band can be grouped to form vectors. But this will not exploit inter-band correlations.

Various approaches such as classified VQ, shape gain VQ, tree-trellis VQ are combined with basic or full search wavelet-VQ.

In [40] blocks of wavelet coefficients are formed of size 8 X 8. These coefficients are taken from different levels. Each block is classified into 4 classes based on variance value. Then each block is divided into subvectors based on variance distribution of the coefficients in each class. Different subvectors use different codebooks. In [41] wavelet coefficients from different resolution and different orientation are combined to form vectors. These vectors are classified into different classes corresponding to vertical and horizontal edges as well as edge and non-edge blocks in the image. Classified vector quantization reduces both edge distortion and computational complexity. PSNR of 33.04 was mentioned at bit rate 0.307 bpp. Biorthogonal symmetrical filter was used for wavelet decomposition. Variance, average energy is mainly used for classification because this criterion separates the vectors remarkably.

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In technique [42] matching code vector is expressed as linear combination of codevectors. This is done at successive passes. At every iteration residual vector i.e. \( r = x - x_n \) is found. 'x' is input vector and 'xn' is codevector approximate and next pass vector is closes to the 'r' found. The process gives good results but requires many search steps.

[43][44] Have introduced the Voronoi lattice VQ as a means for uniform successive refinement of vectors while preserving the mean squared error advantage of lattice quantization. Progressive refinement based on the \( D4 \) lattice, have been applied to wavelet image coding.

Multiresolution tree structured VQ is implemented by [45] Interpolative VQ is implemented in [46] [47]. But very less work seems to be done on wavelet based interpolative VQ.

Basic drawback of VQ is large encoding time. To overcome this problem fast search techniques are suggested. In the presented thesis work main focus is on fast search techniques. These fast algorithms can be grouped into three categories: partial distortion elimination (PDE), triangular inequality elimination (TIE), and mean-distance-ordered search (MOS). Three typical spatial inequality based algorithms are ENNS (Equal-average Nearest Neighbor Search), EENNS (Equal average Equal-variance Nearest Neighbor Search), and EEENNS (Equal-average Equal variance Equal-norm Nearest Neighbor Search) algorithms.

[48] [49] has used partial distance search technique for fast search. Here codebook is arranged in ascending order according to their mean values. Then DWT of codeword is taken. Search is initialized by taking minimum distortion value equal to first dimension difference. Codewords are compared partially. If the codevector gives distortion less than current minimum value, remaining portion of the codevector is compared otherwise codevector is eliminated. If any particular codevector gets eliminated in the processing next codevectors are not compared. The algorithm reduces encoding time to 3%.

In mean distance ordered search [50], codevectors are arranged in ascending order in accordance with their mean value. The search is based on inequality between mean value and distortion i.e. Euclidean distance Difference between mean value of the input vector and codevector is compared. As numbers of multiplications are avoided, search
time is reduced. Also Because of ordered codevectors, split search technique is used to reduce search time further. At the same reconstruction quality of that of input, with codebook size 256 encoding time was reduced to 4.3% approx.

In [48][49][50] ordered codebook according mean values is the important parameter. Also if input image is in spatial domain pixel values are positive. For such case if the mean values of the two vectors are close, they will have minimum distance. But for image in wavelet domain, wavelet coefficients take positive as well as negative values. Best match in the mean values may not satisfy minimum distortion criterion.

Very different approach is taken by [51]. Here Euclidean distance is precomputed offline. Results of all possible xj and yj are precomputed and stored into a large matrix or look up table. Distance between every element of x and y is found by addressing LUT. As subtraction and multiplication is avoided speed increases. However large memory is required for LUT. The size of the LUT depends on vector values. As the wavelet coefficients are in large range size and not integers LUT becomes unpractical.

Very few techniques are tried for fast search VQ in wavelet domain. Khalifa [52] has transformed the image in wavelet domain. He arranged the codebook in ascending order of ratio $h = \sigma^2 / m$, where $\sigma^2$ is the variance ‘m’ is the mean. For input vector also, $hx$ is calculated. Codevector giving closest match is found. Few vectors below and above are searched. 70–80% encoding reduction was obtained at the cost of quality.

In [53] codevector search is based on triangle properties instead of Euclidean distance. A control vector or anchor vector is defined in space. Distance between every codevector and control vector is pre-computed and stored. Codevectors are also arranged in ascending order of the distance. Codevectors are eliminated based on inequality between distance difference in distance between input vector, codevector and control vector. Then search is carried out for limited region. This reduces number of searches and also number of operations, hence makes search technique faster. [54] has used more control vectors to limit search space reduction up to 2.5% was reported by this method. However memory requirement to store distances increases. This technique was also implemented in spatial domain.
fast encoding algorithm for vector quantization is presented. This algorithm makes full use of two characteristics of a vector: the sum and the variance. A vector is separated into two subvectors: one is composed of the first half of vector components and the other consists of the remaining vector components. Three inequalities based on the sums and variances of a vector and its two subvectors components are introduced to reject those codewords that are impossible to be the nearest codeword, thereby saving a great deal of computational time, while introducing no extra distortion compared to the conventional full search algorithm.

Paper by [56] presents a fast codeword search algorithm based on four elimination criteria in ordered Hadamard transform domain, i.e., the first element, the variance, and the norm of the ordered Hadamard transformed vector. The algorithm can reduce the search complexity in the case of high-detail and high-dimensional image vector quantization. Experimental results demonstrate the reduction in coding time up to 6%. Vector quantization is well tried in wavelet domain. VQ in wavelet domain gives more compression than VQ in spatial domain. However fast search techniques implemented above are mostly in spatial domain. Thus there exists scope for finding fast vector quantization technique in wavelet domain.

Fractal compression can also be used in wavelet domain to achieve lossy compression. Barnsley [57] proposed fundamental principle of fractal coding which consists of the representation of an image by a contractive transform. His fixed-point theorem guarantees that within a complete metric space the fixed point of such transform may be recovered by iterated application to an arbitrary initial image. Fractal compression became a practical reality with the introduction by Jacquin [58] of Partition iterated function system, which differs from iterated function system in that each of the individual mapping operates on subset of the image rather entire image. New approach is put up by Kai, Uwe, Barthwel and others [59] in proceedings of ICIP94 is hybrid fractal Image coding technique. They have implemented fractal coding by higher order luminance transformation. All range and domain blocks are transformed to frequency domain. Spectral coefficients of domain block are scaled to approximate to range block. Scaling factor is selected constant for major part of domain block (like in fractal
transform) while those coefficients, which cannot be approximated, are scaled by individual coefficients.

Mostly square range blocks and domain blocks are used. But variety of block partitioning is also used by authors. Quad-tree partitioning, HV partitioning and triangular partitioning are the other partitioning schemes suggested in [60]. Block size is varied depending on details. Adaptive partitioning is given by Matthais Ruhl [61]. Here fractal encoding starts with smaller range blocks. Then range blocks are merged. Merging reduces bit rate. Merging continues till the required bit rate is achieved. While merging, those blocks, which give minimum collage error, are merge first.

It has been noticed by Davis [62] that fractal encoding is equivalent to certain type of wavelet transform coding. The idea is to organize the (Haar) wavelet coefficients in tree and to approximate subtree by scaled copies of other subtrees closer to the root of wavelet tree.

Compression performance in wavelet domain is much superior in wavelet domain. It is even better than JPEG. But large encoding and decoding time is the main problem. Encoding time is much more than decoding. Many authors have tried various schemes to reduce encoding time. Work in present thesis is also concentrated to fast encoding methods.

In fast encoding method by Jean Cardinal [64], feature vector or keys are computed for domain sets and range sets. Search space is divided recursively by hyper planes. This also divides feature vectors into two halves. Then only those domain blocks, the feature vectors of which lie in the same side of the range tree are compared. Quality of reconstructed image decreases with speed up process.

Difference in local variance is used by Lee [65] to eliminate elements of domain pool. Domain blocks are sorted according to their local variance. With defined acceptance criterion search space is limited to small window. Speed factor of 8 was reported at the cost of quality by 0.25db reduction.

Chou-Chen Wang [66] uses correlation between neighbor blocks. The four domain neighbors of range blocks are compared. If MSE between range block and best matched domain block is less than threshold, it is assumed to be best otherwise fast search as in [9] is carried out.
Adaptive search procedure by Tong [67] makes use of inequality relation between difference in standard deviation of range and domain block and matching error. Quality gets affected by 0.87 db however speed increase by factor of 8 is achieved.

Fast encoding can be obtained by classifying blocks into number of categories. [69] Po has done fractal encoding in wavelet domain. He used average intensity of highest band coefficients as classification criterion. According to the sign order coefficients were classified into 8 classes. Further classification into subclasses was carried out on the basis of magnitude. Only those domain blocks, which belong to the same class of that range block, are compared for best match at the cost of 0.6db quality. Speed reduction up to 90% approximately was reported.

In [70] DCT coefficients of range blocks are pre-computed and stored. DCT coefficients of domain blocks are computed and compared with DCT coefficients of range block. Method was tried by selecting only low frequency or only high frequency coefficients for comparison. Depending on the number of coefficients for comparison speed up factor is obtained. When eight low frequency coefficients were selected then speed up factor was eight, but PSNR dropped by 3.10db. But when eight high frequency coefficients were selected with the same speed up factor the quality degraded by .96db.

Fast fractal method used by Li [71] makes use of classification and quadtree partitioning. Here range blocks and domain blocks are classified into shade blocks and non-shade blocks based on variance. If range block is shade block i.e. low variance no search is carried out, range block is approximated by mean value. If domain block is shade block, it is deleted from search pool. Non-shade blocks are divided into four quadrants. Based on variance of quadrants, they are further classified.

The method by [72] is domain kick-out method. Here distortion between range blocks and domain block is calculated using inner product of range blocks and domain blocks. The dissimilar domain blocks are identified and kicked out from search procedure. Computation complexity for rejection is less than actual matching procedure. Therefore speed is reduced. This principle is combined with zero contrast approach. If ratio of inner product of range block and domain block is less than zero bin quantization range then domain block is rejected. With no loss in quality speed factor of 4 was achieved.

Another approach of speed improvement is domain pool reduction. Cheung-Ming Lai, Kin-Man Lam and Wan-Chi Siu [73] have reduced size of domain pool by removing
domain blocks, which are less frequently used. Parameter used for this purpose is entropy. If entropy is more (less probability of selection) than the threshold then the block is eliminated. However method of entropy calculation is not mentioned.

In conventional baseline fractal coder, eight different orientations of domain blocks are considered. For every orientation MSE is calculated. However Trieu-Kien Troung, Jyh-Horng Jeng, Irvin S. Reed el [74] have shown that, there is no need to calculate MSE for each orientation. Redundancy in MSE computation is exploited by calculating MSE in frequency domain using DCT. Further reduction in time is achieved by considering only low frequency coefficients of DCT.

Fractal image compression can be considered as type of self-vector quantization. It shows similarity to mean removed shape gain VQ. VQ and fractal encoding can be combined to get hybrid fractal-VQ compression scheme. Raouf Hamzaoui [75] has given hybrid fractal VQ scheme. Here the input image is approximated by transform VQ. Codebook index is sent to the decoder. From the approximated image domain pool is generated by decimation. Residual image i.e. input image- approximated image is encoded using fractal compression. Thus the reconstruction error is reduced.

In [76] domain blocks are classified into clusters. Cluster centers were computed such that all domain blocks in the given cluster are at equal distance from the center. These cluster centers were used as codebook vectors for VQ encoding. For range block if nearest cluster center is good approximation, it is coded by VQ technique otherwise fractal compression method is used. This reduces coding as well as decoding time at the cost of quality.

Performance of compression algorithms is evaluated in terms of compression ratio or quality. PSNR and mean square error have been used for this purpose since long time. However recent study shows that these quality measures are not reliable. Hence new quality metrics are defines by authors. Most of the quality measures find how close the reconstructed image is with the original image. However human perception is not dependent on pixel-to-pixel difference. Taking on this account human visual system based quality measures are also proposed. They work well and give results very close to subjective measures. However they are computationally complex.

[77] Has evaluated different quality measures for codecs such as SPIHT, JPEG2000.
He showed that single quality measure might not reflect different distortion so group of quality measure should be used.

For Human perception based quality assessment contrast is one of the important parameter. Contrast in the image can be used to measure quality of the image. [78] And [79] have given contrast based quality measure. But human visual systems show different Contrast sensitivity for different frequencies. Contrast sensitivity curve was given as reference.

Yang Lia [80] has used space frequency localization property of the Haar Wavelet to evaluate physical contrast. He represented contrast using transform coefficients. Using Haar wavelet decomposition contrast was defined at every resolution. Contrast at different resolutions was combined with visual effects to give gray scale quality measure. This measure finds contrast mismatch error.

[81] Used integer wavelet to find LMSE i.e. Laplacian mean square error at every resolution. Combined error metrics was used to find quality.

All these quality measure show correlation with subjective quality. Increase or decrease in their values indicates improvement or degradation of the given image. But based on this value we cannot compare quality of two different images.

Natural image signals are highly structured: their pixels exhibit strong dependencies, especially when they are spatially proximate, and these dependencies carry important information about the structure of the objects in the visual scene. Zong Wang [82] has proposed quality assessment metric, which finds structural similarity in the two images to be compared. He has used two parameters to find structural similarity i.e. contrast and luminance. These two parameters were calculated from pixel intensities of the two images. Then structural similarity index was obtained which gave quality of the image. Maximum value of the index can become 1.

Ha shown that this metric shows good correlation with subjective test.

Zuo Wang [83] has defined a new quality metric called as universal quality metric. It can be used for any test image, any viewing condition and any type of distortion. Therefore he called this metric as universals quality index. This quality parameter uses
standard deviation and mean values of the image to calculate index, its maximum value can become 1.

Sankur [84] has done statistical evaluation of quality measures. He has tested 26 types of objective quality measures for this purpose. Mainly these techniques are classified as Pixel difference based measures such as MSE, MAE Minkowsky metrics, Correlation based metrics, Edge quality measure, Spectral distance measure, Context measures, HVS based measure etc. Their statistical behavior was evaluated, in terms of how discriminating they are to distortion artifacts when tested on a variety of images using the analysis of variance method. The measures are then investigated in terms of their mutual correlation or similarity in the form of Kohonen maps.

Sonia Gric [85] and [86] has also checked reliability of various objective measures especially for SPIHT and JPEG compressed images. According to their study MD LMSE NAE are more reliable than PSNR and MSE.

Mark Mitra has also shown similar result. Somewhat different approach is taken by [87] has used masking models of spatial and temporal masking processes. These masking processes model various levels of processing, which occur in HVS. By summation a single valued quality metric is found.

Hosaka plot [88] is a graphical technique for quality measurement. To construct a Hosaka plot, or an h-plot, we measure a pair of features of the reconstructed image and compare these with the corresponding features in the original image. The difference between the two feature vectors generates a vector error measure, which, unlike scalar quantities, allows for a description of not only the amount, but also the type of degradation. Feature vectors used are mean and variance.

Pina Marziliano1, Frederic Dufaux [89] has given method for Blur measurement and ringing artifact measurement. However the method is too complex and not suitable for natural images.
Quality evaluation using ‘Zipf law’, which is power law model is given by [90]. Images are scanned from left to right, top to bottom by 3 x 3 masks are considered for this. Gray scale pixel values are given rank from 0 and highest gets 8. Same value gets same rank. Rank frequency is calculated and presented as double graph. Distance between power plot of original image and distorted image is used to compute quality. For this ‘Zipf quality factor’ is defined. Zero value is used for best quality, 1 is poor quality. Results are more consistent to human perception.

[91] Has given fuzzy logic based similarity measure. Difference between reference image and decompressed image or distorted image is taken and difference image is formed. In the neighborhood of pixels in difference image average of absolute values of neighborhood is calculated with the definition of membership function. Structural similarity is found.

The co-histogram method is used by [92]. Co-histogram is a statistical graph generated by counting corresponding pixel pairs of two images. A co-histogram is two dimensional joint probability distributions of the two images. It shows how the pixels are distributed among combination of two images. It shows how pixels are distributed among combination of two image pixel values. In case of no degradation, co-histogram is strictly diagonal otherwise off-diagonal distribution is not zero. It is quantified by co-histogram symmetry ‘ parameter. It is also useful for blur and rotational measure.

Image quality metrics are evaluated by Eskicioglu [93]. He has evaluated total 12 parameters. They are divided into three groups. Correlation between these parameters and subjective tests was calculated. His evaluation has shown that normalized mean square error is the best parameter for all images. But instead of any single parameter group of parameters should be used because the parameter performance is based on compression technique.

[94] Another very important class of quality parameters is perceptual metrics. Based on perceptual parameter. These metrics take into consideration human perception factors such as contrast sensitivity, luminance adoption, contrast masking and noise masking, supra-threshold artifact, JND testing etc. he proved that quality metrics which
incorporate above factors perform better. However still less work has been carried out on model definitions of these parameters.

We can evaluate performance of VQ or fractal compression in wavelet domain with the help of multiple quality parameters. Wavelet transform gives information of the data in spatial as well as frequency domain. It is also multiresolution in nature. Based on these properties quality metrics can be defined which may perform better than spatial domain metrics.

For certain applications like web image retrieval, lossy to near lossless or lossless compression is required. For such applications quality of the reconstructed image is improves with transmitted bits. This is known as embedded coding.

Embedded coding came into reality due to Shapiro's algorithm [95]. Correlation between coarser resolution and finer resolution was fully exploited in zero tree algorithms. Dependent Relation between coarser and finer coefficients is defined as parent and child relationship. Tree structure formed by these coefficients was coded using small symbol set. Along with the Embedded coding good compression ratio was achieved. SPIHT algorithm [96] used the same dependency in terms of set. Using set partitioning rules compression more than zero trees was achieved. Comparative study of EZW and SPIHT is given in [97].

Variety of embedded coding methods is used by authors other than EZW and SPIHT. Wavelet based image-coding algorithm called successive partition zero coder (SZPC) is given by Wang and Po [98]. It uses hybrid bit scanning and non-causal adaptive context modeling. Wavelet transform coefficients' magnitude range is divided into variable size partition successively. Coefficients are ordered as per their magnitude. Coefficients are scanned using vertical and horizontal scanning i.e. hybrid scanning. Bits are encoded using arithmetic encoder using context modeling.

Method known as SSM (significant switching Mask) is given by Abharatnye [99]. Two types of quad tree coding are used in this method. First type uses standard qudtree coding. If it is found to be less efficient coding is changed to second type. In this method along with quadtree raster scanning of coefficients is used. The results are better than SPIHT for lossless coding.

Lossless coding is required for medical image compression. The method in [100] is combination of VQ and SPIHT for lossless compression. Wavelet tree is vector quantized using dynamic VQ. If distortion between approximated input vector and
selected codevector is more than threshold, vector is coded using SPIHT algorithm until
distortion is less than distortion limit. Performance is improved as compared to SPIHT.
In case of image with 'high frequency' contents, SPIHT does not result into efficient
coding. This is because significant coefficients are present in high frequency range,
which reduces number of zerotrees. For such case hybrid coding method is suggested by
Su [101]. Here wavelet trees are classified as low frequency tree and high frequency
tree based on number of significant coefficients in higher band. Low frequency tree is
coded using conventional SPIHT algorithm. High frequency wavelet tree is coded using
multistage VQ and SPIHT. Results are improved compared to SPIHT.
As SPIHT looses its efficiency as it transmits the lower bit planes, approach
implemented by [102] is based on number of '1's occurring in the given bit plane. The
algorithm uses conventional SPIHT in each bit plane as long as the frequency of '1' s is
less than 0.2, otherwise SPIHT will not be used for that particular bit plane but bit plane
coding is used.

Above methods show that SPIHT though very efficient at low bit rate, does not prove to
be efficient compression method for lossless or near lossless schemes. Therefore either
altogether different approach is to be used or SPIHT should be used along with some
other technique.
Two stages near lossless coder by [103] is algorithm, which identifies the optimum rate
up to which SPIHT is efficient. This rate is the critical rate. For near loss less coding the
image is coded by SPIHT method up-to this rate, above this rate residual image is
scalar quantized and entropy encoded using arithmetic coding. Critical rate is the rate at
which, total entropy of the residual image and bit planes code starts increasing. This
method gives more compression than SPIHT above critical rate.
1.3 Problem definition

- Global problem definition for thesis presented is 'study of wavelet and transform based compression techniques'. Lossy compression techniques such as Scalar quantization, vector quantization, fractal compression and progressive coding technique SPIHT are considered for the study. However study is not only limited to the comparison level, but study aims to enhance the coding strategy by some aspect.

- For any compression scheme quality, compression ratio and complexity are the parameters of comparison. Conventionally PSNR or MSE are used as quality parameters. Literature survey shows that PSNR is not very reliable technique of quality measurement. Subjective quality measurement using MOS test or objective quality measurement using group of quality measures should be done. Hence comparison of the above mentioned techniques using subjective and objective quality measures is necessary.

- From literature survey following problems areas are identified which need to be addressed.
  The various authors have reported compression techniques in wavelet domain, which use vector quantization, fractal compression as well as progressive coding techniques. Vector quantization and fractal compression techniques are computationally complex. This results in large encoding time. Hence it is important to find fast encoding techniques for VQ and fractal at the no cost or small cost of quality.

- Fast encoding algorithms are reported for VQ but mostly in spatial domain. While very less work exists on fast fractal encoding in wavelet domain. There is also scope for hybrid coding techniques i.e. combinations of coding methods such as vector and fractal to improve speed of encoding.

- In the process of compression, artifacts such as edge ringing, blockiness are reported. These artifacts are difficult to quantify. Their effects on perceptual quality are also less studied. This is also considered as problem area.
1.4 Outline of the thesis

Chapter II – compression performance of wavelet families are evaluated in this chapter. Coiflet, Mayer, Daubechies and Biorthogonal wavelets are used for this purpose. Filter length, symmetry of filter and number of decomposition levels are the variable parameters while comparison. Entropy histogram shape, correlation, variance are also compared in spatial and wavelet transform domain.

Chapter III- scalar quantization and arithmetic entropy encoding is described in this chapter. Context based arithmetic encoding is also considered in this chapter. Compression ratios of uniform and nonuniform using single or separate quantizers are implemented compared. Adaptive Context based coding with different context definition are evaluated by implementation. In this chapter, new context classification is proposed.

Chapter IV – with the background of scalar quantizer, further improved quantization technique is tried here. ‘Same orientation all levels’ and ‘same level all orientation VQ’ methods are discussed.
Three new fast search VQ methods namely Interpolative VQ, TIE based classified VQ, and priority based VQ are presented here

Chapter V- This chapter is about fractal compression. Theory of fractal compression is given in this chapter. Two new fast search methods are suggested here. First method uses reduced domain pool size. Second method is fast search method for color images. Fractal encoding for color images takes very large time. Our method reduces search time to great extent at the cost of small amount of quality.

Chapter VI- embedded coding techniques such as EZW and SPIHT are discussed in this chapter. These techniques enjoy benefit of correlation between wavelet coefficients at different subbands. These techniques are progressive transmission techniques. Large coding gain results at low rate but coding efficiency decreases with subsequent passes. Using standard SPIHT code available such critical coding rates were found and above
This rate image was coded using binary arithmetic coding. Results were compared for images.

**Chapter VII**- In this chapter various quality measures are listed. Subjective, objective and graphical measures are included. All the algorithms implemented in above algorithms and JPEG 2000 is compared using these measures. New wavelet domain based contrast measure is implementation, New edge artifact and blur measure is also implemented this chapter.

**Chapter VIII**- Result and conclusions- details of experimentation, new algorithms suggested are given at the end of every chapter. Comparative analysis of all techniques is done in this chapter.