Review of Fractal Transform based Image and Video Compression

R. E. Chaudhari
St. Francis Institute of Technology
Mumbai, Maharashtra
India

S. B. Dhok
Visvesvaraya National Institute of Technology,
Nagpur, Maharashtra
India

ABSTRACT
Fractal Compression is a new technique in the field of color and video compression. This technique has grabbed much attention in recent years because of very high compression ratio that can be achieved. It also provides interesting interpolation features to zoom the images. Hybrid schemes incorporating fractal compression and speedup techniques have achieved better compression ratio compared to pure fractal compression. Fractal Transform compresses color images and videos better than gray scale images because the color planes are highly correlated to each other and video sequences are temporally correlated. This review represents a survey of the most significant advances in the field of fractal grayscale/color image and video compression. In this paper, we review various types of approaches for fractal based compression scheme and some of the latest techniques to improve the encoding time as well as decoded image/video quality.

General Terms
Fractal Image and Video Compression

Keywords
Fractal Transform, Color and video compression, Iterated function systems, Block Classification and Feature Extraction.

1. INTRODUCTION
With the ever increasing demand for images (gray or color), video sequences, computer animations and multimedia technology, data compression remains a critical issue regarding the cost of storage space and large channel bandwidth (transmission times). While JPEG currently provides the industry standard for still image compression there is ongoing research in alternative methods. Barnsley [1] introduced an attractive encoding method of image compression referred to as fractal image compression which is based on Iterated Function System (IFS). Fractal image compression exploits natural affine redundancy present in typical images to achieve high compression ratio in a lossy compression format. An image is modeled as a set of fractals and is encoded using the feature of self-similarity. Fractal image compression gives some desirable properties like resolution independence, fast decoding, and high compression ratio, but it has very high encoding time.

The basis for fractal transform is the collage theorem [2]. The collage theorem defines that for an input image S, a new set (attractor) W(S) is described by the union of n number of sub-images, each of which is formed by applying a contractive affine transformation wi on S is as per (1).

$$W(S) = \bigcup_{i=1}^{n} w_i(S) \qquad (1)$$

This contractive transform ensures that, the distance between any two points on transformed image will be less then the distance of same points on the original image [1]. Therefore, when a given digital image is modeled as a set, it may be partitioned into sub-images (called as Range blocks), each of which can also be treated as an attractor with its own set of contractive transformations that comprise a local iterated function system. The advantage of partitioning an image in this manner is that the smaller range blocks are less complex and can thus be described by simpler local IFS. The union of these simplified local IFS codes forms the original image's Partitioned Iterated Function System (PIFS) [2].

With the development of multimedia technology, color image processing has become more important. A true color image is represented by 24 bits per pixel in a RGB color space with each component occupying 8 bits. But many different color image representations techniques are used in practice [3]. Generally each of red, green or blue color components is compressed separately using gray-level fractal image coding algorithm by treating it as a single gray-scale image.

Similarly video sequences are compressed by removing spatial redundancy and temporal redundancy using intra frame coding and inter frame coding respectively. Block matching motion estimation is a vital process for many motion compensated video coding standards. Generally video codec contain different types of frame data; intra-frames and predicted frames. An intra frame is a full image compressed in some manner and can generally be reconstructed independently of other frames. A predicted frame contains information regarding only the differences between the previous frame and the current frame; construction of the complete frame requires the previous frame to be available, which itself may be constructed from predicted frames.

The rest of the paper is organized as follows. In section 2, discuss the basic fractal image compression scheme and its classification. Then in section 3 describe different approaches of gray scale image compression. Different ways of color image and video sequence compression are explained in section 4 and 5 respectively. Finally conclusion is made in section 6.

2. FRACTAL IMAGE COMPRESSION BASIC SCHEME
General fractal image block encoder is as shown in Figure 1. The image is partitioned into non-overlapping of blocks, denoted as a range blocks. The goal for the encoding is to determine, for each range block, a best matching block, denoted as domain block, under an affine mapping. The domain block should be larger in size than the range block to which it maps in order to fulfill contractivity property.

In the encoding phase of fractal image compression, the image of size N x N is first partitioned into non-overlapping range blocks Ri, {i = 1, 2,…..p) of a predefined size B x B. Then search for a matched block is conducted in the image by partitioning the image into overlapping domain blocks Dj, (j = 1, 2, ….q) of size 2B x 2B. The number of range block is p = $(N/B)^2$, while the number of domain block is q = $(N-2B+1)^2$. The range-domain matching process initially shrink the domain block down to the size of a range block by pixel averaging and a each domain block is applied with eight basic square block symmetry operations by rotating 90 degrees clockwise the original and the mirror domain block [4]. To obtain the best match for each range block the entire domain pool must be searched for best affine transformation Wi which minimizes the distance between Ri and Wi(Dj) using (2).

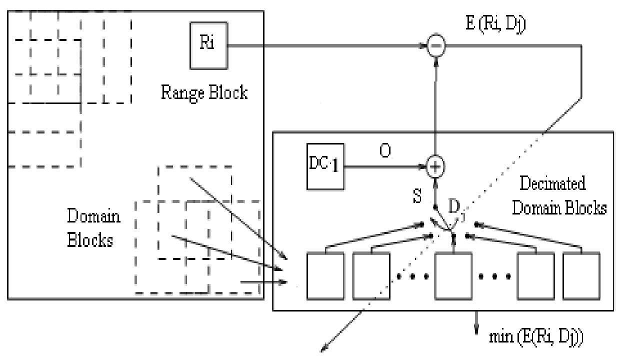
$$W_i\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} a_i & b_i & 0 \\ c_i & d_i & 0 \\ 0 & 0 & s \end{bmatrix}\begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} e_i \\ f_i \\ o \end{bmatrix} \quad (2)$$

With pixel coordinates (x, y) and gray level z. the parameters (ai, bi, ci, di) represents simple geometric transformation and (ei, fi) are the spatial transformation and (s, o) represents gray scale intensity transformation.

The Root Mean Square RMS {E(Ri,Dj)} metric is used to measure the distance as per (3), for a range block with n pixels, each with intensity ri and a decimated domain block with n pixels, each with intensity di the objective is to minimize the error.

$$E(R_i, D_j) = \sum_{i=1}^{n}(s.d_i + o - r_i) \quad (3)$$

The coefficient s represents a contrast factor, with |s| < 1.0 to make sure that the transformation is contractive in the luminance dimension, while the coefficient o represents brightness offset. The parameters that need to be placed in the encoded bit stream are s, o, index of the best matching domain, and symmetry index. For sequentially coded range block the biggest drawback is exhaustive searching to locate matched domain block which increases encoding time.



DC.1 - Block of size N x N with values ones

Fig 1: General fractal image block encoder

Several methods have been proposed to overcome this problem. In this review paper various new approaches are describe to minimize the encoding time and different ways to compress color image as well as video sequence using fractal based coding. Figure 2 shows the classification of fractal based image and video compression approaches.

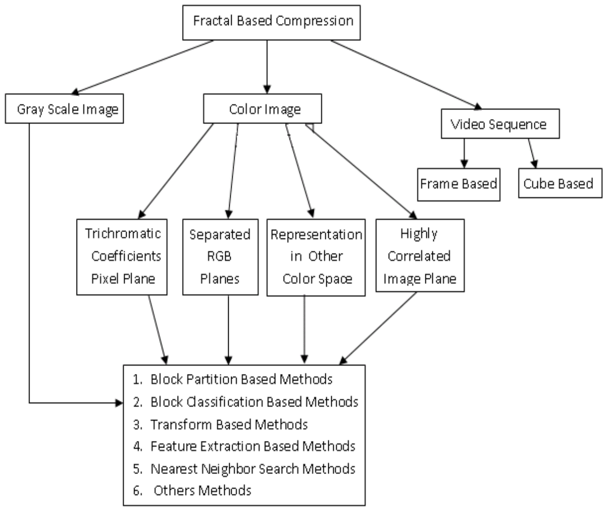


Fig 2: Classification of fractal based compression approaches

3. GRAY SCALE IMAGE COMPRESSION

Using fractal transform, higher image compression ratio can be achieved than the JPEG scheme but the encoding time also increases. The focus of major research in fractal image compression is on improving the speed of compression while keeping the quality of decompressed image comparable to the existing schemes. Here it described a review of new techniques of fractal image compression to improve the speed of compression as well as the quality of an encoded image. These techniques are classified as shown in Figure 2 and are described as follows.

3.1 Block Partition Based Methods

In any Fractal compression system the first decision is to choose the type of image partition for the range blocks formation. A wide variety of partitions have been investigated. Fixed size square blocks are the simplest possible partition [2]. The Quad tree approach [5] divides a square image into four equal sized square blocks, and tests each block to see some criterion of homogeneity. If a block does not meet the criterion then it is further divided into four sub-blocks. Other partitioning schemes are HV partition that divides the image [6] into two parts horizontally and vertically based on the image texture, Polygonal block partitions of different shapes [7], Irregular partition [8], Delaunay triangulation [7] which is constructed using seed points and is adapted to the image by adding extra seed points in regions of high image variance, Isosceles triangle partition [9], and Hexagonal representation of pixel (Pseudo Spiral Architecture) [10]. A Quad-tree partition provides best rate distortion in a comparison with polygonal, HV partition. Irregular partition performs better than fixed squared block and quad-tree partition but some sort of interpolation is required because there is no simple pixel-to-pixel correspondence between domain and range blocks.

A new approach to speed up the encoding time based on character track while searching for the appropriate domain block using HV partition is proposed and results are compared with the quad-tree partition approach [6]. Three character standards are defined, based on the distributing of brightness, the gray difference and the gray ratio of range block.

Satellite images are highly complex in nature, these images are compressed using quad-tree partitioning [11], with minimum threshold and Huffman coding [12]. Urban images achieved high compression and better PSNR than rural images because urban images contain more fractal nature than the rural satellite images.

Ali [13] proposed a non-overlapping domain blocks with quad-tree partition with only 4 values of contrast scaling. Quad-tree Recomposition (QR) [14], using circular linear array of processors is employed and utilized in a parallel pipelined fashion [15, 16]. In QR base methods, sub-blocks from lowest level of an image are iteratively recombined into larger blocks for fractal coding, at upper level no need to perform all calculation for MSE; initially blocks can be classified as gray-shade or edge blocks. For complex image this method is better than quad-tree decomposition. Combination of quad-tree decomposition (QD) and QR [17] is introduced, in first phase QD for gray shade blocks and in second phase QR for edge blocks are performed.

3.2 Block Classification Based Methods

The most common approach for reducing the computational complexity is the classification scheme. In this scheme range and domain blocks are grouped in classes according to their common features.

In Entropy based with two domain pools (AP2D-ENT) approach [18], the domain blocks are classified into two pools, one contains odd position and other contains even position domain blocks. Initially search is done in the even domain pool if the absolute entropy difference between range and domain is less then predefined threshold. Otherwise the search for the best matched domain block is done in odd domain pool. Quality of image decreases slightly but speed up factor increases to 8 with respect to full search.

Graph-based image segmentation approach [19] is used to separate an input image into many different logic areas according to image content and to construct search space for each logic area. Each logic area is encoded using adaptive threshold quad-tree approach for fast image compression.

DCT of block in one direction (horizontal/vertical) [20] is used for feature extraction and blocks are classified into 4 types of edges. The structure similarity (SSIM) index is used instead of MSE to reduce computation complexity. It encodes 15 times faster than full search.

New classification method based on approximation error is proposed to defer range/domain comparisons [21]. In coding process all domains are compared with preset block (mean of range blocks), and approximation error is computed and stored in a KD-tree. The binary tree data structure is used for feature vector management.

Regional search is proposed [22] for compression as well as decompression. The searching of domain block is carried out in the limited search region instead of whole image. Partition the image into sufficiently large non-overlapping search region. Based on average pixel value of blocks, range/domain blocks are classified into K number of classes [23] and heuristic search strategy is used.

Domain pool reduction adaptive partitioning [24] is proposed using diamond domains to reduce the number of range partitions and block classifications. Domain blocks are classified and domain pools are also reduced according to their means and variances [25]. Jayamohan used Fractal Dimension (FD) [26] to classify the domain blocks and height balanced binary search trees is used for storing domain information ordered in terms of the FD. The domain pool is prepared dynamically by comparing the fractal dimension of range block with that of the domains. Box counting or differential box counting [27] methods are used to calculate FD. William used a feature vectors as HOG descriptor [28] and a clustering algorithm is applied to classify the domain blocks in k clusters.

3.3 Transform Based Methods

Lossless acceleration method is based on codebook coherence using FFT based cross correlation with irregular image partition [8] and FFT base fast convolution with quad-tree partition [29] by down sampling image and range block with padding zeros. They are used to reduce the time complexity of fractal image encoding and particularly well suited for lossless compression. The most traditional (lossy) acceleration schemes lose a large part of their efficiency. Time reduction is achieved without sacrificing image quality.

FFT based block matching [30] technique using Hadamard product is also used. Each decimated blocks are represented as a vector using suitable scanning and the transformation of each decimated domain block by inverse scanning all possible circular shift of the corresponding vector. High speed up factor can be achieved with reduction in PSNR by about 1.5-2.5dB. Troung introduced Hadamard Transform [31] and Discrete Cosine Transform (DCT)-inner product [32] methods to reduce the complexity for MSE computation. All of the redundant computations are eliminated in parallel implementation of 8 orientations for MSE computation by proper arrangement of coefficients. These methods are about six times faster than that of baseline method with almost similar image quality. Optimized domain block searching in frequency domain like Fast DCT coefficient-based metric operation [33] is proposed by converting fixed size square block into 1D array to calculate DCT. In another paper [34] active 8 DCT coefficients are selected instead of always low band data. A hybrid fractal/DCT a technique is proposed by Curtis [35] in which pruned DCT is employed whenever the quality of the decoding block is good else fractal image compression technique is used.

Haar wavelet sub-tree quantization scheme [36] is introduced for analyzing fractal block coder. Haar wavelet transform coefficients are used [37] to find mapping similar regions within an image. Pure-Fractal and Wavelet-Fractal compression techniques [38] are applied to cDNA micro array images which exhibit high degree self-similarity.

3.4 Feature Extraction Based methods

In adaptive pixel value difference scheme [39], domain and range block comparison for best match is preformed only if the range block pixel value difference is less than the scaled domain block pixel value difference. The adaptive scaling parameter β (varying between 1.0 and 2.0) for domain block is used at each quad-tree partition depth. In addition to this scheme if the normal variance of domain block [40] is greater than that of range block then best matching process is performed with fixed size block. Both the schemes reduce the encoding time while maintaining good quality of decoded image. Another paper suggested an entropy difference of range and domain block [41] instead of pixel value difference with the same adaptive threshold approach for medical / satellite images. To reduce the computation complexity of fractal encoding and adaptive search algorithm [42] is proposed. For each range block check is done to verify whether domain block meet the adaptive search condition (4) for a given value of tolerance θ along with optimal bit allocation scheme for the simultaneous quantization of the scaling and affine parameters.

$$|std(R) - std(D)| \geq \theta.std(R) \quad (4)$$

Normalized one-norm [43] and extreme difference feature of normalized block with standard deviation [44] are also used to sort the domain blocks in an ascending order respectively. If the respective difference between range and domain is minimum and error $E(R_i,D_j) \geq D_{min}$ then domains Dj to D1 are kicked-out from the domain pool. It increases the compression rate with speedup factor of more than 4 with same decoded image quality.

In certain approach [45], predefined values for contrast scaling factor instead of searching for these values and domain blocks with entropies greater than threshold are considered. The optimum value of's' depends on the size and entropy of range block. Another approach is used to reduce encoding time, by removing the domain blocks with high entropy [46] form the domain pools as many of these domains are never used in a fractal coding.

In non-iterative scheme [47], mean and variance of each range block is calculated and form each mean value generate domain image. If variance is smaller than threshold then block is coded by block mean otherwise it uses affine transformation with the same size of range and domain block thus avoiding contractive procedure.

The number and the positions of the local extreme points in row direction within an image block are also good classification features and the three layers tree classifier based on these features can be utilized [48].

Quasi-lossless image compression [49] method separates minimum sized domain blocks based on maximum variance and marked them as a feature rich blocks. These blocks are compressed by using any lossless compression techniques and the remaining blocks are compressed by using fractal coding technique. This method is modified by using self organizing neural network based machine learning [50] to improve encoding speed.

3.5 Nearest Neighbor Search Methods

Fractal image compression is equivalent to multi-dimensional nearest neighbor search [51]. It operates in logarithmic time as compared to the conventional linear search method and it can easily integrate into existing implementations of classification method to accelerate the speed.

Novel prediction and sub block based algorithm [52] is proposed in which variable size range block tries to find the best matched domain block within generated search window, which is based on mean value of motion vector of relevant 4 neighboring domain blocks. Otherwise the range block is again decomposed into four quadrants based on recursive quad-tree decomposition principle.

Interblock correlation search [53] technique uses four domain blocks of the neighboring range blocks as good candidates of the input range block because of high correlation between them. Otherwise, local variance based fast fractal coding method is performed to find best match domain block.

Correlation information feature [54] describes the type of block it self and reflected similarity between the blocks and its corresponding template. Blocks are classified into two classes according to orientation features and sorted in a descending order within each class. For every range block the nearest neighbor domain block is obtained and achieves better reconstructed image quality.

3.6 Other Methods

A local search operator for Quantum Evolutionary Algorithm (QEA) [55] is proposed. After the convergence of population, a simulated annealing algorithm is performed on possible solution until algorithm escapes from local optima. Particle Swarm Optimization technique [56] is also used for searching matched domain blocks. The range and domain pools for above method are classified into three types of regions according to third level of discrete wavelet coefficients.

Another approach is to reconstruct the original image using hard threshold [57] and then partition into non-overlapping range and domain blocks with smaller and larger size respectively.

New searchless iterative function system [58, 59] encodes the range blocks based on fixed location of domain blocks. Fractal code does not contain the coordinates of the domain range matched pairs. Therefore, the size of range block can be 2 X 2 pixels. It is more efficient and suitable for hardware FPGA implementation because does not require iterative operations. VLSI parallel architecture (systolic structure) using local data communication [60] for flexible size fractal image coding based on quad-tree partitioning is proposed.

Combination of multi-scale analysis and neural networks [61] is used to reduce the coding complexity using GSOFM network to classify the image blocks into different types.

The kick-out and zero contrast conditions [62] are used to reduce encoding time. The single kick-out condition eliminate unmatched domain blocks and if the absolute value of 's' is less than threshold then value of s is set to 0. These two conditions increase the speed up factor up to 25% of baseline search.

4. COLOR IMAGE COMPRESSION

Color image compression has much larger encoding time than the gray scale image due to existence of three planes in color image. The three RGB color planes are highly correlated to each other. This feature is exploited to further reduce the encoding time by representing RGB planes into useful formats.

4.1 Separated RGB Planes

One of the basic methods is [63] to split RGB into 3 components and compress them separately by treating each color component as a single gray scale image. Extensive experiments are carried out with different size of domain and range blocks [64] on color space images. Recurrent Iterated Function Systems (RIFS) [65] encodes a set of image planes at the same time, in which not only the intra-mapping defined between blocks of the same image plane but also the inter mapping between blocks of different image planes is performed with contraction constraint. The multispectral images such as RGB color images have both the inter similarity and the intra-similarity property.

4.2 Highly Correlated Image Plane

One color plane which shows maximum correlation with other two planes is called as a reference frame. The reference frame is encoded first using quad tree partition scheme [66] and for the remaining two planes, range blocks are approximated by domain blocks matched for the range block at same spatial location in reference plane with possibly different scaling factor. Only slight modifications of the fractal code for one color plane are necessary in order to describe the other planes with sufficient accuracy [67]. Hybrid algorithm using fractal and Vector Quantization [68] which utilizes highly correlated plane encoded in wavelet domain is also possible.

4.3 Trichromatic Coefficient Pixel Plane

The proposed approach first determines the pixel's trichromatic coefficients within the homogeneous blocks formed using quad-tree partitioning. For each block variance of pixel trichromatic coefficients must be within threshold value. Then, each block is represented by mean value of the pixel's trichromatic coefficient ratios and a one-plane image is composed and compressed by fixed size square block fractal coding [69]. Pseudo Spiral Architecture [70, 71] using optimized domain blocks [72] with average minimum distance to minimize encoding time, Isosceles triangle segmentation [9] to improve coding efficiency are some of the other methods of trichromatic coefficients pixel plane based color image compression.

4.4 Representation in Other Color Space

RGB components are transformed to YUV components in some compression methods. The UV components are down sampled and then each component of YUV is coded individually. Moment features [73, 74] and DCT [75] are used to determine the block descriptor, which in turn is utilized to classify the image blocks. Adaptive zero-mean method [76] is proposed in which average of the range block is used instead of traditional offset parameter. By adding symmetry predictor in previous method using first order centralized moments [77] it is possible to reduce the number of isometric trails from 8 to one trail approach is proposed. RGB image is transformed to YIQ color space and then I&Q band are down sampled [78], the domain blocks which are having high entropies and/or high distance ratio of domain/range blocks are removed and then the encoding algorithm is applied. Daniele proposed a L*a*b* color space to represent color image and signature features of range and domain blocks are compared by means of [79] Earth Mover's Distance (EMD) measure to identify similarities within color images.

Hybrid fractal/DCT combination [80] is applied on both RGB and YCbCr color space by partitioning the image into 8 X 8 block size and low band DCT quantized block is obtained. The fractal coding is used to compress the image with same size of range and domain blocks.

5. VIDEO SEQUENCE COMPRESSION

Moving image sequence exhibits a high temporal correlation; the domain range mapping becomes more effective if the size of domain block is same as that of range block. It can be interpreted as a kind of motion compensation. As far as video compression is concerned, there are two basic fractal compression methods being used most frequently. One is known as the frame-based compression [81] and the other is known as cube-based compression [82]. Advantages and disadvantages of each method including bit rate versus image/video quality are discussed in [83] based on the similarities in the implementations.

5.1 Frame Based Compression

In frame-based compression, the compression code is computed and stored for every frame, in which intra frame or inter frame self-similarity may be used. First frame in the sequence and the difference between the predicted and the actual new frame are fractal-coded [84] using block wise contractive affine transformations. For inter frame predictive coding second order geometric transformations for motion compensation is used. Fractal codes are computed for each frame by comparing domain blocks from previous frame with range blocks of current frame and the result are tested for different size of range blocks [85] using fixed block partitioning scheme.

Wavelet Transform based fractal video coding [86] scheme achieves compression through pyramid wavelet transform. Each video frame is decomposed into multiresolution sub bands and then organized into a set of wavelet sub trees to represent motion activities. These wavelet sub trees are classified into motion and non-motion sub tress. The coding of non-motion sub trees is straight forward and simple, while the motion sub tresses are adaptively separated and then encoded using variable tree size fractal coding. The domain sub trees are extracted from previous reconstructed frame not from current frame itself; only one step fractal decoding is enough to obtain the approximation of original frame.

A novel approach, based on the circular prediction mapping (CPM) and the noncontractive interframe mapping (NCIM) [81] is proposed, CPM should be contractive for the decoding process to converge, while the NCIM need not be contractive. In CPM, four frames are encoded as a coding group, and each frame is predicted block wise from the four-circularly previous frames, and the following frames are sequentially encoded with NCIM's by employing the previously reconstructed frame.

Fast Block-matching Motion Estimation called cross-hexagon search algorithm (NHEXS) is also frame based compression [87, 88] to improve the encoding speed and the compression quality. New object-based monocular and stereo video compression scheme is proposed [89], which employs the object-based CPM/NCIM fractal coding and quad tree-based disparity estimation/compensation scheme. Using an object based concept, Zhu proposed a region-based fractal coding scheme with fixed size partition [90] alternative to the block based approach, the regions or objects can be defined by a previously computed segmentation map and are encoded independently of each other. In this scheme output video quality is slightly (1-2dB) degraded as compared to block based approach.

5.2 Cube Based Compression

In the cube-based compression, a sequence of images is divided into groups of frames (GOF), each of which in turn is partitioned into non-overlapped cubes. The compression code is computed and stored for every cube. Matching search procedure for each of the range cubes requires more computational complexity. Wang [91] proposed a parallel matching search procedure using partition into small tasks and implements it in two distributed computing environments, one using DCOM (Distributed Component Object Model) and the other using .NET Remoting technology, based on a local area network.

Fast low bit rate 3D searchless fractal video encoding [92] using cube based technique with large sized only one domain cube initially. The cube volume is subdivided until a target threshold is reached.

Three dimensional fractal video coding with spatial and temporal contraction [82] scheme introduces Fractal Transform Coding (FTC) which is a unification of fractal and transform coding. No motion compensation is used. FTC is used to exploit intra and inter cube redundancies of an image cube.

Hybrid fractal video coding [93] exploits the redundancy present in different scales. The neighborhood vector quantization, as a generalization of translational motion compensation, is used for removing both intra and inter-frame coherences. Hybrid compression methods are also explored by combining cube-based and the frame-based compression techniques using fixed-size partition [94], and an adaptive partition to achieve high compression ratio [95].

6. CONCLUSION

Fractal image compression is based on affine contractive transforms and utilizes the existence of self-symmetry in the image. In this paper, many key ideas and approaches are discussed which are available in the literature for fractal based compression over the past decade or more. Though fractal technique has a lot of attractive features but the large encoding time is still drawback of this technique. In most of the methods encoding time is decreased using either classification of domain blocks with useful features or by various ways of partitioning image, but output quality of decoded image decreases slightly. The compression of color images are based on correlation of RGB components. The color RGB plane is converted into YUV, YIQ, YCbCr formats or into single planes and compression is achieved in new formats. Video sequences are highly temporally correlated and it is compressed by using either cube based or frame based methods to further increase the compression ratio.

7. REFERENCES

[1] Barnsley M. F., "Fractal Image Compression", Notices of the AMS, pp. 657-662, June 1996.

[2] Y Fisher, “Fractal Image Compression”, SIGGRAPH-1992 Course Notes.

[3] Rafel C. Gonzalez, Richard E. Woods, “Digital Image Processing”, Second Edition, Pearson Education Asia, 2005

[4] Fisher, Y.: Fractal Image Compression: Theory and Applications. Springer, New York, 1995

[5] K. M. S. Soyjaudah, I. Jahmeerbacus, “ Fractal Image Compression using Quadtree Partitioning”, International Journal of Electrical Engineering Education 38/4, October-2001.

[6] Guorui Jiang, Yuzhuo Zhong, Shiqiang Yang, “Fast Fractal Image Compression Based on HV Partition”, SPIE Conference on Multimedia Storage and Archiving Systems, vol. 3846, 1999.

[7] B. Wohlberg, G.D. Jager, “A Review of Fractal Image Coding Literature”, IEEE Trans. on Image Processing, vol. 8, no. 12, pp. 1716-1729, Dec. 1999

[8] Hannes Hartenstein, Dietmar Saupe, “Lossless Acceleration of Fractal Image Encoding via the Fast Fourier Transform”, Elsevier, July-2000.

[9] Yuli Zhao, Zhiliang Zhu, Hai Yu, “Fractal Color Image Coding Based on Isosceles Triangle Segmentation”, IEEE, Computer Society, International Workshop on Chaos-Fractal Theory and its Applications, pp. 486-490, 2010

[10] Huaqing Wang, Meiqing Wang, Tom Hintz, Xiangjian He, Qiang Wu, “Fractal Image Compression on a Pseudo Spiral Architecture”, Proceedings of the Twenty-eighth Australasian conference on Computer Science – Vol. 38, pp. 201-207, 2005

[11] Veenadevi S. V., A. G. Ananth, “Fractal Image Compression of satellite Imageries”, International Journal of Computer Applications, vol. 30, no. 3, pp. 33-36, September-2011.

[12] Veenadevi.S.V., A.G.Ananth, “Fractal Image Compression Using Quadtree Decomposition And Huffman Coding” Signal & Image Processing : An International Journal (SIPIJ), Vol.3, No.2, pp. 207-212, April 2012

[13] Fakhiraldeen H. Ali, Azzam E. Mahmood, “Quad-Tree Fractal Image Compression”, Al-Rafidain Engineering, vol. 14, No. 4, 2006.

[14] David.J.Jackson, Wagdy Mahmoud, William A. Stapleton, T. Patrick, Gaughan, “Faster fractal image compression using Quad tree Recomposition”, Elsevier, 1995.

[15] D. J. Jackson, Wagdy Mahmoud, “Parallel Pipelined Fractal Image Compression using Quadtree Recomposition”, The Computer Journal, vol. 39, No. 1, 1996.

[16] W. A. Stapleton, Wagdy Mahmoud, D. J. Jackson, “A Parallel Implementation of a Fractal Image Compression Algorithm”, IEEE Proceedings of 28th Southeastern Symposium on System Theory, pp. 332-336, 1996.

[17] Wagdy Mahmoud, D. J. Jackson, “Improved Quadtree Decomposition/Recomposition Algorithm for Fractal Image compression”, IEEE Proceedings Southeastern, pp. 258-263, 1999.

[18] Sofia Douda, Abdelhakim EI Imrani, Abdallah Bagri, “A New Approach for Improvement of Fractal Image Encoding”, International Journal on Computer Science and Engineering, vol. 2, no. 4, pp. 1387-1394, 2010.

[19] Hai Wang, “Fast Image Fractal Compression with Graph-Based Image Segmentation Algorithm”, International Journal of Graphics, vol. 1, no. 1, November-2010.

[20] C. M. Kung, W. S. Yang, C. C. Ku, C. Y. Wang, “Fast Fractal Image Compression Base on Block Property”, IEEE Proceedings of International Conference on Advanced Computer Theory and Engineering, 2008.

[21] Daniel Riccio, Michele Nappi, “ Defering Range/Domain Comparisons in Fractal Image Compression”, IEEE Proceedings of the 12th International Conference on Image Analysis and Processing, 2003.

[22] Pou-Yah Wu, “Fast Fractal Image Compression”, IEEE Proceedings International Conference on Information Technology: Coding and Computing, pp. 54-59, 2000.

[23] Lin Hu, Qi-An Chen, Dan Qing Zhang, “An Image Compression Method based on Fractal Theory”, The 8th International Conference on Computer Supported Cooperative Work in Design Proceedings, vol. 1, pp. 546-550, 2003.

[24] Boukelif Aoued, “Accelerating Fractal Image Compression by Domain Pool Reduction Adaptive Partitioning and Structural Block Classification”, 3rd International Conference: Sciences of Electronic,

Technologies of Information and Telecommunications, Tunisia, 2005.

[25] Said El-Khamy, Mohamed Khedr, Ahmad Al-Kabbany, "Efficient Fractal Image Coding Using Adaptive Domain Pool Reduction Technique", IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, pp.62-65, 2007.

[26] Jayamohan M., K. Revathy, "An Improved Domain Classification Scheme Based on Local Fractal Dimension", Indian Journal of Computer Science and Engineering (IJCSE), Vol. 3 No. 1, pp. 138-145, Mar 2012

[27] K. Revathy, M. Jayamohan, "Dynamic Domain Classification For Fractal Image Compression", international Journal of Computer Science & Information Technology (IJCSIT), Vol 4, No 2, pp. 95-102, April 2012.

[28] William Robson Schwartz, Helio Pedrini, "Improved Fractal Image Compression Based On Robust Feature Descriptors", International Journal of Image and Graphics World Scientific Publishing Company, pp.1-17, 2011.

[29] Dietmar Saupe, Hannes Hartenstein, "Lossless Acceleration of Fractal Image Compression by fast Convolution", IEEE International Conference on Image Processing, Sept.-1996

[30] M. Ramkumar, G. V. Anand, "An FFT-based Technique for Fast Fractal Image Compression", Elsevier Signal Processing, vol. 63, issues 3, pp. 263-268, December-1997.

[31] J.H.Jeng, T.K.Truong, J.R.Sheu, "Fast Fractal Image Compression Using the Hadamard Transform", IEE Proc.-Vis. Image Signal Process, Vol. 147, No. 6, pp. 571-574, Dec.2000.

[32] Trieu-Kien Truong, Jyh-Hong Jeng, Irving S. Reed, P. C. Lee, Alan Q. Li, " A Fast Encoding Algorithm for Fractal Image Compression Using the DCT Inner product", IEEE Transactions on Image Processing, vol. 9, no. 4, April-2000.

[33] Korush Kiani, Keyvan Jaferzadeh, hadi rezaei, Samaneh Gholami, " A New Simple Fast DCT Coefficients-Based Metric Operation for Fractal Image Compression", IEEE Computer Society 2nd International Conference on Computer Engg. And Applications, 2010.

[34] O.C. Au, M. L. Liou, L. K. Ma, "Fast Fractal Encoding in Frequency Domain", IEEE Proceedings of International Conferences on Image Processing, 1997.

[35] K. M. Curtis, G. Neil, V. Fotopoulos, "A Hybrid Fractal/DCT Image Compression Method", International Conference on Digital Signal Processing, vol. 2, pp. 1337-1340, 2002.

[36] Geoffrey M. Davis, "A Wavelet Based Analysis of Fractal Image Compression", IEEE Transaction on Image Processing, vol.7, Issue 2, pp. 141-154, 1998.

[37] H. Krupnik, D. Malah, E. Karnin, "Fractal Representation of Images via the Discrete Wavelet Transform," in IEEE 18th Conv. of EE in Israel, Tel-Aviv, Mar. 1995.

[38] Mohammad R. N. Avanaki, Hamid A., Reza Ebrahimpour, " Evaluation of Pure-Fractal and Wavelet-Fractal Compression Techniques", ICGST-GVIP Journal, vol.9, issue 4, Auguest-2009.

[39] Venkata Rama Prasad, Ramesh Babu, "Fast Fractal Image Compression Based on Domain-Range Pixel Value Difference", Global Journal of Computer Science and Technology, vol. 10, issue 4, pp. 67-73, June-2010.

[40] Gohar Vahdati, Elham Afarandeh, Mehdi Yaghoubi, "Improvement Speed of Fractal Image Compression through Gray Level Difference and Normal Variance", IEEE Computer Society International Conference on Soft Computing and Pattern Recognition, 2009.

[41] Venkata Rama Prasad, Ramesh Babu, "Fast Fractal Compression of Satellite and Medical Images Based on Domain-Range Entropy", Journal of Applied Computer Science & Mathematics, no. 9 (4), 2010.

[42] Chong Sze Tong, " Fast Fractal Image Encoding Based on Adaptive Search", IEEE Transactions on Image Processing, vol. 10, no.9, pp. 1269-1277, September-2001.

[43] Hsiu-Niang Chen, Kuo-Liang Chung, Jian-Er Hung, "Novel Fractal image Encoding Algorithm using Normalized On-Norm and Kick-Out Condition", Elsevier Image and Video Computing, vol. 28, pp. 518-525, 2010.

[44] Gaoping Li, "Fast Fractal Image Encoding Based on the Extreme Difference Feature of Normalized Block", IEEE International Conference on Computing and Intelligent Systems, 2009.

[45] H. Miar Naimi, M. Salarian, "A Fast Fractal Image Compression Algorithm Using Predefined Values for Contrast Scaling", Proceedings of the World Congress on Engineering and Computer Science USA, October-2007.

[46] M. Hassaballah, M. M. Makky, Youssef B. Mahdy, "A Fast Fractal Image Compression Method Based Entropy", Electronic Letters on Computer Vision and Image Analysis 5(1):, pp. 30-40, 2005.

[47] Hsuan T. Chang, Chung J. Kuo, "A Novel Non-Iterative Scheme for Fractal Image Coding", Journal of Information Science and Engineering 17, pp. 429-443, 2001.

[48] Jinshu Han, "Speeding up Fractal Image Compression Based on Local Extreme Points", IEEE Proceedings of 8th ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing, 2007.

[49] Bhavani S., K. Thanushkodi, "A Novel Fractal Image Coding for Quasi-Lossless Medical Image Compression", European Journal of Scientific Research, Vol.70, No.1, pp. 88-97, 2012.

[50] Bhavani S., K. Thanushkodi, "A New Algorithm for Fractal Coding Using Self Organizing Map", Journal of Computer Science 8 (6): pp. 841-845, 2012.

[51] Dietmar Saupe, "Accelerating Fractal Image Compression by Multi-Dimensional Nearest Neighbor Search", IEEE proceeding Data Compression Conference, pp.222-231, 1995.

[52] Kuo-Liang Chung, Chung-Hsiang Hsu, "Novel Prediction and Subblock-based Algorithm for Fractal

Image Compression", Elsevier Chaos Solution and Fractals 29, pp. 215-222, 2006.

[53] Chou-Chen Wang, Chaur-Heh Hsieh, "An Efficient Fractal Image-Coding Method Using Interblock Correlation Search", IEEE Transactions on Circuits and Systems for Video Technology, vol. 11, no. 1, January-2001.

[54] Q. Wang, D. Liang, Sheng Bi, "Fast Fractal Image Encoding Based on Correlation Information Feature", 3rd International Congress on Image and Signal Processing, vol. 2, pp. 540-543, 2010.

[55] Hossein Mohamadi, Ali Nodehi, Mahamad Tayarani, " A Local Search Operator in Quantum Evolutionary Algorithm and its Application in Fractal Image Compression", 2nd IEEE International Conference on Computer and Automation Engineering, vol.2, pp. 710-715, 2010.

[56] Yih-Lion Lin, Wen-Lin Chen, "Fast Search Strategies for Fractal Image Compression", Journal of Information Science and Engineering 28, pp. 17-30, 2012.

[57] Anupam Garg, "An Improved Algorithm of Fractal Image Compression", International Journal of Computer Applications, Vol. 34, No.2 pp. 17-21, November 2011

[58] D. J. Jackson, Haichen Ren, Xianwei Wu, Kenneth G. Ricks, "A Hardware Architecture for Real-Time Image Compression using a Searchless Fractal Image Coding Method", Journal of Real-Time Image Processing, Springer, Vol. 1, Issue 3, pp. 225-237, April-2007.

[59] Songpol Ongwattanakul, Xianwei Wu, David Jeff Jackson, "A New Searchless Fractal Image Encoding Method for a real-Time Compression Device", International Symposium on circuits and Systems, vol. 4, pp. III- 957-60, May-2004.

[60] S. Lee, S. Omachi, H. Aso, "VLSI Architecture for Quadtree Based Fractal Image Coding", IEE Proc.-Computer Digital Technology, vol. 148, No. 4/5, Sept.-2001.

[61] Guo Jianwei, Sun Jinguang, "An Image Compression Method of Fractal Based on GSOFM Network", IEEE Congress on Image and Signal Processing, 2008.

[62] Cheung-Ming Lai, Kin-Man Lam, Wan-Chi Siu, "A Fast Fractal Image Coding Based on Kick-Out and Zero Contrast Conditions", IEEE Transactions on Image processing, vol. 12, No. 11, pp. 1398-1403, 2003.

[63] Moltedo L., Nappi M., Vitulano D., Vitulano S., "Color Image Coding Combining Prediction and Iterated Function Systems", Signal Processing, Vol. 63, pp. 157-162, 1997.

[64] N. Koli, M. Ali, "Lossy Color Image Compression Technique using Fractal Coding with Different Size of Range and Domain Blocks", International Conference on Advanced Computing and Communications, Surathkal, India, pp. 236-239, Dec. 2006.

[65] Kwon Kim, Rae-Hong Park, "Color Image Coding Based on Recurrent Iterated Function Systems", Optical Engineering, Vol. 37, No. 2, pp. 551-555, February 1998.

[66] Jiao H L, Chen G., "A Color Image Fractal Compression Coding Method", Journal of Software, Vol. 14, No. 4, pp. 864-868, 2003.

[67] Bernd Hurtgen, Paul Mols, Stephan F. Simon, "Fractal Transform Coding of Color Images", Visual Communications and Image Processing, SPIE Proceeding, 1994.

[68] M. B. Khambete, M.A. Joshi, "Fast Hybrid Fractal –VQ Color Compression in Wavelet Domain", IEEE Region TENCON, pp.1-4, 2005

[69] Zhaohui Li, Liang Zhao, Nei Y. Soma, "Fractal Color Image Compression", IEEE Proceedings of the 13th Brazilian Symposium on Computer Graphics and Image Processing, pp. 185-192, 2000.

[70] Thakur Nileshsingh V, Dr. O. G. Kakde, "Fractal Color Image Compression on Pseudo Spiral Architecture", IEEE Conference on Cybernetics and Intelligent Systems, June-2006.

[71] Thakur Nileshsingh V, Dr. O. G. Kakde, "A Novel Compression Technique for Color Image Database", International Conference on Advanced Computing and Communications, Surathkal, India, pp. 240-243, Dec. 2006

[72] Thakur Nileshsingh V, Dr. O. G. Kakde, "Color Image Compression on Spiral Architecture using Optimized Domain Blocks in Fractal Coding", IEEE 4th International Conference on Information Technology, pp. 234-242, 2007.

[73] Loay E.George, Eman A. Al-Hilo, "Speeding-up Fractal Colored Image Compression Using Moments Features", International Conference on Computer and Communication Engineering, pp. 1303-1307, May-2008.

[74] Eman A. Al-Hilo, Loay E. George, "Speeding-up Fractal Colored Image Compression Using Moments Features", IEEE Digital Image Computing: Techniques and Application pp. 486-490, Dec-2008

[75] Loay E. George, Nevart A. Minas, "Speeding Up Fractal Image Compression Using DCT Descriptors", journal of Information and Computing Science, Vol. 6, No. 4, pp 287-294, 2011.

[76] Loay E.George, Eman A. Al-Hilo, "Fractal Color Image Compression by Adaptive Zero-Mean Method", IEEE Computer Society, International Conference on Computer Technology and Development, pp.525-529, 2009

[77] Loay E. George, Eman A. Al-Hilo, "Speeding-up Fractal Color Image Compression Using Moments Features Based on Symmetry Predictor", IEEE, Computer Society, Eighth International Conference on Information Technology: New Generations, pp. 508-513, 2011.

[78] Tawfiq A. Al Assadi, Zena Hussain Khalil, "Image Compression by Using Enhanced Fractal Methods" Journal of Qadisiyah Computer Science and Mathematics, vol.3, Issue 1, pp. 1-10, 2011.

[79] Daniele D. Giusto, Maurizio Murroni, Giulio Soro, "Fractal Coding of Color Images using Earth Mover's Distance", Second International Mobile Multomedia Communications Conference. Italy, 2006.

[80] Chandan Rawat, Sukadev Meher, "A Hybrid Image Compression Scheme using DCT and Fractal Image Compression", The International Arab Journal of Information Technology, 2011.

[81] Chang-Su Kim, Rin-Chul Kim, Sang-Uk Lee, "Fractal Coding of Video Sequence Using Circular Prediction Mapping and Noncontractive Interframe Mapping", IEEE Transactions on Image Processing, Vol. 7, No. 4, April 1998.

[82] Kai Uwe Barthel, Thomas Voye, "Three Dimensional Fractal Video Coding", IEEE Proceedings, International Conference on Image Processing, Berlin, vol. 3, pp. 260-263, 1995.

[83] T. C. Ferguson, H. R. Wu, ``Rate Versus Distortion Comparison of Fractal Video Techniques", Proceedings of 1997 Picture Coding Symposium, pp.457-461, September, 1997.

[84] Andonova S., Popovic D., "Video Coding Using Fractal-Based Image Compression", IEEE International Conference on Systems, Man and Cybernetics, vol. 1, pp. 343-348, 1994.

[85] Kulkarni M. V., Kulkarni D. B., "Analysis of Fractal Video Coding Using Fixed Partitioning Scheme", Journal of Signal and Image Processing, ISSN: 0976-8882, Vol. 3, Issue 4, pp.126-129, 2012.

[86] Ying Zhang, Lai-Man Po, Ying-Lin Yu, "Wavelet Transform Based Variable Tree Size Fractal Video Coding", IEEE Proceedings of International Conference on Image Processing, Vol. 2, pp. 293-297, 1997.

[87] Kamel Belloulata, Shiping Zhu, Zaikuo Wang, "A Fast Fractal Video Coding Algorithm Using Cross-Hexagon Search for Block Motion Estimation", International Scholarly Research Network Signal Processing, volume 2011, Article ID 386128, 2011.

[88] Shiping Zhu, Yangshuan Hou, Zaikuo Wang, Kamel Belloulata, "A Novel Fractal Video Coding Algorithm Using Fast Block-matching Motion Estimation Technology", International Conference on Computer Application and System Modeling, china, vol. 8, pp. v8-360-v8-364, 2010.

[89] Kamel Belloulata, Shiping Zhu, "A New Object-Based System for Fractal Video Sequences Compression", Journal of Multimedia, Vol. 2, No. 3, pp. 17-25, June 2007.

[90] Shiping Zhu, Yangshuan Hou, Zaikuo Wang, Kamel Belloulata, "Fractal Video Sequences Coding with Region-Based Functionality", Elsevier Inc. Applied Mathematical Modelling, Vol. 36, pp. 5633-5641, 2012.

[91] Meiqing Wang, Zhehuang Huang, Choi-Hong Lai, "Matching Search in Fractal Video Compression and its Parallel Implementation in Distributed Computing Environments", Elsevier Inc. Applied Mathematical Modelling, Vol. 30, pp. 677-687, 2006.

[92] Victor De Lima, William R. S., Helio Pedrini, "Fast low Bit-Rate 3D Searchless Fractal Video Coding", IEEE 24th SIBGRAPI, pp. 189-196, 2011.

[93] ZhenYao, RolandWilson, "Hybrid Fractal Video Coding With Neighbourhood Vector Quantisation", IEEE Proceedings, Data Compression Conference, UK, 2004.

[94] Meiqing Wang, Choi-Hong Lai, "A Hybrid Fractal Video Compression Method", Elsevier, International Journal of Computers and Mathematics with Applications 50, pp. 611-621, 2005.

[95] Meiqing Wang, Rong Liu, Choi-Hong Lai, "Adaptive Partition and Hybrid Method in Fractal Video Compression", Elsevier Inc. Computers and Mathematics with Applications, Vol. 51, pp. 1715-1726, 2006.