Fractal Image Compression: A Review

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Abstract

Image compression is one of the steps of image processing. It deals with the transmission and storage of images which are digital in nature. Fractal images are self similar images where each individual part is same as that of the whole. The major objective of fractal image compression is to lessen the size of image by retaining the quality of image. It is categorized under block base image compression techniques which looks for similar parts in the image and encode these parts before sending to the receiver. At the receiver side these encoded parts are used to reconstruct the image. The major drawback of fractal image compression is that it requires abundant amount of time for this encoding. In this paper we comprehensively reviewed various available fractal image compression techniques and approaches to decrease the encoding time of FIC and to get improved quality of reconstructed image.

Keywords: *Fractal image coding, Fractal image compression, Iterated function systems*

1. Introduction

Use of image processing is in enormous areas nowadays. Since the development of recent image acquisition devices, image processing becomes even more considerable. The only drawback is the immense amount of time taken to execute image processing techniques. The most fascinating property of fractals is its self similarity property. Self similarity means individual parts of image are same as that of the whole image. In other words when image contains parts which are exactly the copies of it, that image is called as fractal image. When in image compression we are using this property of fractals, is called fractal image compression.

1.1 Overview Of Fractal Image Compression:

The terminology fractal was coined by Benoit Mandelbrot (1983) [1]. The term fractal emerges from the fractional type values that the dimension of fractal objects can suppose. The key property of fractals is self similarity. So fractal objects show similar detail irrespective of the extent at which they are viewed. Most objects lose detail when one zooms in for a closer view. Fractals are always the consequence of some type of frequentative process. A second property possessed by fractals is dimension that can be integer or non integer. Fractal image compression is a technique for compression of images in which redundant information i.e. self similar part of image in case of fractals or repeatedly occurring part of natural image is coded by a set of transformations. These transformations are sent to the decoder as compressed part. Later original image is reconstructed from these transformations using number of iterations. As soon as images of two iterations are identical, iterations are stopped and original image is recovered.

1.2 Contractions:

Contractive transformation is one of the types of affine transformation. It moves points closer together.

An affine transformation can be defined as; transformation f is contractive for following condition:

$$d(f(p),f(q)) <= c\, d(p,q) \qquad (1)$$

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Where c is a constant in range of 0 and 1 and distance of (p,q) gives the distance between the two points p and q. From the above equation it is clear that a contractive transformation makes things smaller.

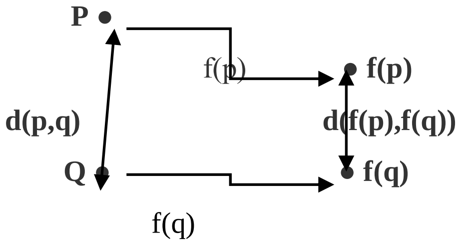

Fig.1 Contraction mapping

The constant value c represents a **factor of contraction** and it indicates how much the contractive transformation brings points closer. So in contractive transformation by applying same transformation again and again on same point it will end up in some fixed result.

Mathematically an affine transformation on any point p can be written as

d (f(p),f(q)) <= c d(p,q) (2)

Where f (p) yields the result of applying f n number of times to p. So contractive transformation can be written as:

f (p)- >z if n-> infinity (3)

So as n gets bigger f (p) tends to a fixed value z.

By repeating the transformation iteratively any starting pattern is transformed into a repeating pattern with the same structure at any level of detail which in turn generates a fractal [1]. In fractal image compression, to make the mapping of domain and range block contractive mapping a condition is added that the domain block has to be shrunk down onto the range block.

In FIC first given image is separated into overlapping domain and non-overlapping range blocks. Fractal encoding is a process to find best matched domain block, or transformations for achieving best matched domain block, for each range block from the domain blocks. The domain location and the coefficients need to be stored for each transform after encoding [1]. So saving transformations will require less memory as compared to original data. Thus in fractal encoding process image is converted into fractal codes. In the decoding reverse process is done, in which a set of fractal codes are converted to image. So fractal encoding involves computational complexity. Since more number of iterations is required to find the fractal patterns in an image, it takes longer time. The decoding process is much simpler as it transforms the encoded codes to the image. The basic idea is that certain geometric transformations like combinations of scaling, rotation, translation, horizontal, vertical flip - ultimately reach a fixed point. Compression of image is done by storing these affine transformations and sending it to the receiver as compressed part. In the decoding process the transformations are applied repeatedly to an arbitrary starting image, to recreate the input image or very similar to the original input image.

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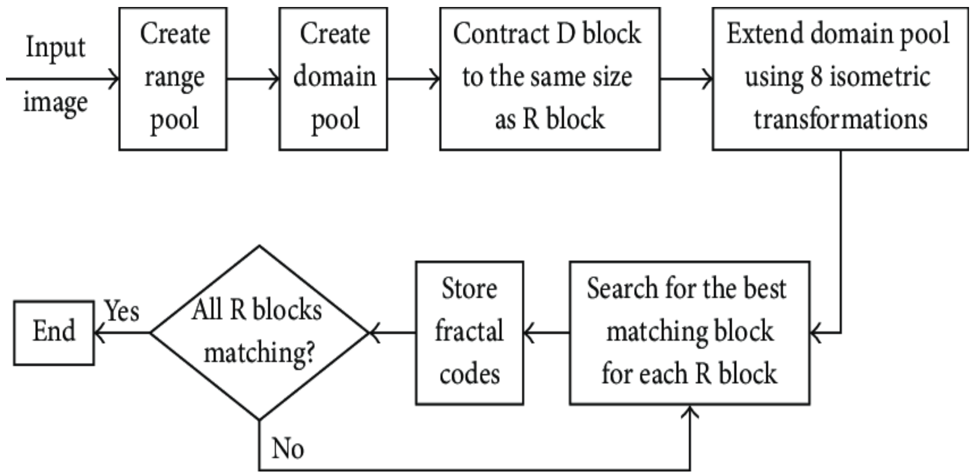

Fig.2 Fractal Image Coding

Domain pool comprises of domain blocks present in an image and overlapping of those blocks. More overlapping of domain blocks results in large number of domain blocks which in turn increases the size of domain pool. In this case number of comparisons of domain block and range block will be more which will make encoding slower. But compression ratio will be better. Less overlapping of domain blocks gives less number of domain blocks comparatively and so coding time will be less but compression ratio will be less. So, proper selection of overlapping of domain blocks is crucial in fractal image coding.

2. Related Work on Fractal Image Coding

Erjun Zhao Dan Liu **[2]** discussed different categories to which fractal image compression methods belong. Categories like methods based on block segmentation which involves encoding as a method to find similar transformations, for each non-overlapping range block from the overlapping domain blocks is discussed. The domain location and coefficients are only to be stored for each transform after encoding. Number of blocks severely affect compression ratio. So methods such as region segmentation and cross-searching methods are suggested. Region based methods divide image into regions and then search each region for the possible transform so as to improve the encoding time. As searching whole image for the possible affine transform of the region may take longer time so cross-searching methods are used with region segmentation for more efficiency. Another category includes expanded self-similar fractal serial image coding method. In this approach, blocks are split into four classes depending on complexity of blocks. Then for each range-child block, the searching is done in the same class that will decrease the search space and improve the compression ratio.

Suman K. Mitra **[3]** involves image compression using IFS and probabilities. It divides the given image up to a certain predefined level or up to that level at which there is no possibility of next division. At every step of partitioning, the image or sub image is divided into four quadrants. The Markov operator is calculated and the approximation of the image by means of the invariant measure of the Markov operator is done at every partitioning. This technique is very fast in image encoding. Multiscaling division is used to find the contractive maps and corresponding probabilities. To speed up the encoding in fractal image compression (FIC) a fast fractal image coding and decoding algorithm (FFIC) was proposed in **[4]** based upon the quadtree block partitioning. Fisher classification method is found to improve the encoding process drastically. To get better block operations, domain pools are organized in advance; PC memory is used for blocks to make it a faster technique. In FFIC algorithm there is a concept of multithreading which makes compression faster. To decrease the encoding time in fractal coding a new technique was proposed in **[5]** that reduce number of comparisons of domain and range block which in turn reduces the encoding time which is otherwise most time consuming part. In this method the variance Criteria is taken into account for partitioning. Varying size blocks (4×4, 8×8, and 16×16) have been considered. The results demonstrate that the blocks produced by

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quadtree partition, vary with partitioning parameters (mean, SD and block size). Small values of mean and standard deviation had resulted in acceptable image quality and high compression ratio and vice versa. In encoding step the desirable value of mean and standard deviation are found out. Decoding works in a similar way to classical method. Nadia M. G. Al-Saidi, Aqeel H. Ali [**6**] modify original fractal image coding employing the concept of fractal dimension that uses image complexity as an index for the domain blocks in order to improve the searching process for each range block. As most of the time in fractal image coding is consumed in the comparison of domain and range blocks, improvement is suggested in the way of comparison of domain and range blocks. In this paper box counting approach (Improved Differential Box Counting algorithm) which involves two important factors like box size in each grid and total number of boxes to cover the image so as to calculate fractal dimension is emphasized. Also differential box counting approach in which improvement is done in terms of calculation of fractal dimension is suggested. This considers maximum and minimum values of grey levels in a fixed box in the image. This approach is proved to be an efficient approach and helped in reducing encoding time. Later to improve encoding time and decoding image quality, edge based- FIC approach along with nearest neighbor technique is proposed in **[7].** In this k-nearest neighbor search method is used for range and domain block pool searching. Alexandru Mihai Vulcan, Maximilian Nicolae **[8]** focused on encoding time of FIC algorithms**.** And graphics processing units (GPU) can provide support to achieve this. Compression is achieved by iteratively encoding similar parts. Because on CPU such operations take more time, the graphics processing units can provide some support. The same process for finding and encoding similar parts from the image in parallel can run using GPU architecture. But in this process there is a use of CPU too, to partition an image into range blocks and then best matching domain block finding process is executed in parallel in GPU which is an iterative process and can run in parallel. Shiping Zhu, Juqiang Chen **[9]** investigates methods based on variance, search strategy, based on search range and based on partition. In variance based FIC and in methods based on search strategies speed of fractal coding is improved, but gives poor quality of decoded image. In search range methods encoding time depends on search range, it is directly proportional to size of search range. Therefore to choose a sound search range is a vital task.

In Partition-based methods block partitioning is the most important decision to be taken about. If the size of blocks divided is very small, it will take long coding time and for large size blocks, the coding quality will be affected. These partitioning methods are elaborated in **[10]** as fixed size squared block such as domain and range block, quadtree partitioning methods employing recursive splitting of selected image quadrants, horizontal-vertical partitioning, triangular partitioning in which a rectangular image is divided diagonally into two triangles. This method is flexible as compared to horizontal-vertical partitioning scheme. A new approach is proposed in 2018 **[11]** based on deep data pipelining for implementing FIC. In this approach an image is partitioned into non-overlapping range and overlapping domain blocks where domain block comprises four range blocks. Also two same operations can be performed immediately using two processor units. Later time for encoding is reduced by exploiting the innately high extent of relationship amid pixels in the vicinity areas and best matching domain block search is done in the nearby blocks only. R. Praisline Jasmi et al. **[12]** presents comparison of FIC, DWT and Huffman Coding. Parameters like mean square error, Compression Ratio and Peak Signal to Noise Ratio (PSNR) are involved in comparison to evaluate the performance of above methods, FIC is proved to be an efficient technique. To make FIC a faster technique **[13]** proposed an approach making use of local features so as to reduce search space. A new local binary feature is introduced. Extracted feature is used to calculate distinction among range and domain blocks by using Hamming distance method instead of least-square method. A superior feature extraction can make a distinction between one block from other non-similar blocks. By skipping irrelevant range–domain blocks matching, it increases the searching speed with diminutive loss of quality. To decrease the computational time of FIC **[14]** proposed a hybrid approach using spiral architecture. This technique works on spiral addition for translation and multiplication for rotation of image. Proposed method compared with FIC and proved to have considerable improvement in compression ratio and PSNR. **[15]** Proposed sparse fractal image compression to speed up FIC using combination of absolute value of Pearson's correlation coefficient and sparse coding. Orthogonal sparse fractal algorithm based on image texture is proposed in **[16]. V**ariance feature vectors of domain blocks and range blocks are identified then the similarity measure matrix is calculated between them. Orthogonal Matching Pursuit (OMP) algorithm **[17]** is useful for orthogonal sparse grey level matching process. After finding the index of matched domain block, fractal code of the range block is recorded. Here parameters are used to finish block searching. By adjusting the values of the parameters encoding time as well as image quality both can be put in a good window. Also results proved to beat the results of method proposed in [15].

In FIC critical decision to be taken is about the type of image partition. Available partitions are fixed size squared block, quadtree, horizontal vertical partitioning and triangular partitioning. Quadtree partitioning totally reduces the number of MSE computations. Methods like DWT, DCT and fractal based methods have drawback of low compression ratio and high encoding time.

Veenadevi.S.V. and A.G. Ananth **[18]** proposed FIC with quadtree decomposition and Huffman encoding. Many approaches were projected to diminish the encoding time but that result in degradation of reconstructed image after decoding. To solve that issue some hybrid approaches combining fractal coding and other coding methods were investigated. Quadtree approach here is a combination of quadtree partitioning and Huffman coding. This approach gives better compression for images having fractals. Another hybrid approach was proposed by Padmavati et al. **[19]** that combines DCT and fractal quadtree decomposition with Huffman encoding of threshold value 0.2. In proposed algorithm, quadtree fractal image compression is used along with DCT. Later Huffman coding is used to give improved compression ratio. It is found that this hybrid approach reduced the encoding time with fruitful PSNR value; achieve high CR, with good image quality as compare to the fractal compression method using quadtree decomposition of image while Utpal Nandi et al**. [20]** proposed a classification strategy that decreases the encoding time of FIC maintaining CR and PSNR almost equal to its counterpart. Another approach using quadtree partitioning is presented in 2019 in **[21]** in which original image is divided into even part and odd part respectively. One part is divided using quadtree decomposition of a range of thresholds. Then complete encoding of fractal codes is done using Huffman Coding. While in decompression for the generated bit codes, Huffman decoding is applied to decode the image. This scheme gives a lower time intricacy, as well as, increased CR and acceptable PSNR.

Ashwini V. Ingole et al. **[22]** illustrates the use of FIC in video compression as video is a combination of images. Coding techniques for both within the frame and between the frames i.e. intraframe and interframe coding is discussed. Fractal image compression is used in each frame for encoding. For displacement of pixel position from previous frame to next frame, interframe coding aims at lowering temporal redundancy and intraframe coding. Motion vector is calculated using frames. Motion estimation algorithms may be region-based, pixel-based and block-based. To calculate MV, pixel-based algorithm holds a threshold value that varies from pixel to pixel. Due to dependencies among the pixels, it is not preferable. Region based technique need more computation time and is complex while parallel approach is explored in **[23]** for motion vector estimation. Shailesh D. Kamble et al. **[24]** used finite automata to represent an image. The automata theory based coding technique seeks out the equivalent portion of image and regular expression is used to identify the address of each considered sub image. It results in high CR, acceptable image/video reform quality, fast decompression time and reduced coding time. All above approaches proved to be better than earlier approach of motion estimation **[25]** in which motion vector estimation is on the basis of high movement zone and low movement zone of image.

M.Salarian, H. Miar Naimi **[26]** proposed a new FIC algorithm whose main focus is on diminishing the pool size also contrast scaling factor(S) is calculated previously to diminish the coding time considerably. In traditional FIC algorithm whole image is partitioned into domain-blocks which in turn increased number of comparisons of range, domain. In this algorithm domain pool comprises of domain blocks having entropy greater than specified threshold value which will decrease the size of domain pool as compared to in previous approaches and that will

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decrease the number of comparisons of domain and range block. Also range blocks are fissure into four range blocks by using quadtree partitioning method to take part in encoding process. This approach has reduced the encoding time considerably. While in **[27]** domain pool size is optimized by changing the overlapping of domain blocks. The number of domain blocks formed in domain partitioning is represented in terms of image size, range size. It is directly proportional to image size while indirectly proportional to range size. Whereas to decrease the search space another approach i.e. FIC with neural network is used in **[28]** in which position of range block is feed to the trained system as input and system in turn gives relevant domain-range pairing. It is an iterative procedure. Due to reduced search space encoding time is improved but compression ratio remains unaffected. To circumvent the iterative process in the decoding phase, the mean image is used in both compression and decompression in **[29]** in iteration-free fractal mating coding process for mutual image compression which is an improvement over FMC **[30]** scheme. FMC algorithm works on inter image matching and perform encoding and decoding operations on multiple images simultaneously. But as the number of images increases, time for decoding also increases which is a disadvantage of this scheme.

Kuldeep Mander et al. **[31]** discussed Block Truncation Coding technique in which basic idea is to reduce the image size which occupies a smaller amount of space in memory and it will be simple to transmit. Thus, BTC is used for compression. After compression, DWT with spline interpolation give decompressed image. The process is suggested in order to view the changed pixels of images after compression of two images. The wavelets and interpolations provide enhanced compressed images that follow the steps for its encoding and decoding processes. To get decompressed images the process will go either by the inverse of a BTC or by DWT and interpolation. The inverse of BTC provides a decompressed image with distortion. Therefore, the paper suggests using DWT with interpolation to decompress images. The PSNR value is calculated and on comparing the proposed technique with the existing ones, it has been found that the proposed method outperforms the most common existing techniques and provides better results in comparison with existing techniques. Ekta Borkar et al. **[32]** proposed image compression technique using wavelet transform. This approach made use of fractal techniques with SPIHT wavelet coding to get upgraded decoded image. For better compression a different approach was used in **[33]** in which polynomial interpolation was involved. DWT was used in preprocessing step and remove any complexity followed by Contrast Limited Adaptive Histogram Equalization method which divides the images into relative regions followed by histogram equalization application to each region. Enhanced polynomial interpolation by including maximum regions of the image attains better CR.

3. Results

Table 1. Results

Paper id	Authors	Findings
[1]	Arnaud and Jacquin	1) Decoded image is free of edge degradation. And very similar to the original.
[2]	E. Zhao and D. Liu	Notably Irrelevant Check based FIC is faster as compared to fractal coding method dependent on child-block classification.
[3]	S. Mitra	1)Extremely fast in image encoding 2) Fast when compared with GA based fractal image compression technique
[4]	M. Sharabayko and N. Markov	1) Suggested method for improvement in the compression ratios and PSNR values. 2) More suitable for compression of high resolution Urban satellite imageries.

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[5]	N.Abdul Jalil Salih	For high image quality, small values of SD and mean are required but will lead to low compression ratio, and vice versa.
[6]	N. M. G. Al-Saidi and A. Ali	The encoding time is better than original FIC method by employing use of fractal dimension.
[7]	R.Gupta et al	Acceptable decompressed image is achieved using Nearest neighbor technique.
[8]	A. Mihai et al	Speedy compression obtained by using the support of GPU.
[9]	S. Zhu and J. Chen	Fast encoding method for FIC is suggested.
[10]	Ankit Garg et al	Analyze the performance of FIC and JPEG. Decompression of FIC faster than JPEG but takes more time to compress than JPEG.
[11]	A. Malik et al	Encode a large size image very fast with reasonable PSNR and CR.
[12]	R.P. Jasmi et al	Comparing results of 3 methods, CR of Huffman is high than other and PSNR of fractal is better than other two.
[13]	K. Jaferzadeh et al	Proposed technique made FIC faster than the full search method while maintaining the quality of the decompressed images.
[14]	Mohammed Ismail. B and T. B. Reddy	Comparing proposed method with BFIC & SA gives improved PSNR, CT and CR. Also it Decrease computational time and improve image metrics.
[18]	Veenadevi V. and A. Ananth	Fast encoding method using quadtree partitioning and Huffman method is suggested.
[19]	S Padmavati and V Meshram	Proposed method decrease the encoding time with productive PSNR value, high CR while maintaining image quality.
[20]	U Nandi et al	Reduces encoding time of FIC maintaining compression ratio and PSNR
[21]	Hasanujjaman et al	Suggested scheme reduces time complexity, as well as, gives increased CR and acceptable PSNR.
[26]	M.Salarian and H. M. Naimi	Achieves compression in considerable lower time.
[27]	V Chaurasia et al	Proposed method with optimized domain pool size gives high-quality image with reasonable encoding time.

4. Conclusion

After analyzing the different methods suggested in various research papers, we conclude that one of the challenging task in FIC is to find best domain that will map to a range. In general, the size of domain pool has noticeable effect on the performance of FIC. It is directly proportional to the number of comparisons that will be carried out to find best domain range matching. So larger pool size imply more comparisons which will make encoding more time consuming. Also this step is exceptionally computationally exhaustive. For small images, size of domain pool will be smaller which involves less number of domain blocks in comparison step and thus image quality will be inferior. In contrast for bigger images the compression quality will be enhanced, mainly when proper partitioning of domain -range block is used. To get reduced compression time, search space should reduce. This is possible by using different partitioning schemes available.

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