A Review On Fractal Image Compression

Geeta Chauhan, Ashish Negi

Abstract: This study aims to review the recent techniques in digital multimedia compression with respect to fractal coding techniques. It covers the proposed fractal coding methods in audio and image domain and the techniques that were used for accelerating the encoding time process which is considered the main challenge in fractal compression. This study also presents the trends of the researcher's interests in applying fractal coding in image domain in comparison to the audio domain. This review opens directions for further researches in the area of fractal coding in audio compression and removes the obstacles that face its implementation in order to compare fractal audio with the renowned audio compression techniques.

Index Terms: Compression, Discrete Cosine Transformation, Fractal, Fractal Encoding, Fractal Decoding, Quadtree partitioning.

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1. INTRODUCTION

THE development of digital multimedia and communication applications and the huge volume of data transfer through the internet place the necessity for data compression methods at the first priority [1]. The main purpose of data compression is to reduce the amount of transferred data by eliminating the redundant information to keep the transmission bandwidth and without significant effects on the quality of the data [2]. In addition, the compression time should be minimized. Image and audio are the most common medium used in communication between the end users along with the video. Many techniques are used to compress these multimedia files and they exhibit various degrees of compression rate and quality. The data compression is mainly classified into lossy and lossless compression techniques [3]. Lossless compression techniques have the advantage that the size of the original and the compressed data is the same. In addition, the reconstructed data is exactly the same as the original one [4]. However, the compression rate is normally lower than lossy techniques. There are several instances of type of compression techniques, RLE, Huffman, and arithmetic coding. In lossy compression, some of the data is lost during the compression process in order to reduce the size of the compressed file. Such techniques are widely used on the internet. DCT, DWT, VQ, and FC are examples of lossy compression techniques which can be applied to both image and audio files [5]. This study discusses the improvement on the fractal coding and shows the performance of applying it on image and audio files.

2 FRACTAL THEORY

The history of fractal compression belongs to the mathematician Benoit B. Mandelbrot who first introduced term fractal in the field of geometry in 1977 in his book entitled The Fractal Geometry of Nature. Later, this idea was applied to the image as a compression technique with the method of Iterated Function System (IFS) by Barnsley in 1988. In 1992 ArnodeJacquin finally used Partitioned Iterated Function System (PIFS) and collage theory in order to practically implement the fractal coding algorithm [6]. The basic idea behind FIC is to represent the image by a set

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of contractive transformations through exploiting the self-similarity in the image parts using PIFS. The encoding process consists of three sub-processes: first, partitioning the image into non-overlapped range and overlapped domain blocks, second, searching for similar range-domain with minimum error and third, storing the IFS coefficients in a file that represents a compress file and use it decompression process while the decoding process is a straightforward process [4]. Figure 1 and Figure 2 illustrate the two main processes. FIC have several characteristics which are an asymmetric process, high compression ratio, good reconstructed image quality, and fast, straightforward decoding process. However, the encoding process is time-consuming since the exhaustive search process is required for complex computations [7, 8]. In literature, many techniques were presented to overcome the large encoding time.

It is worth to mention that many studies in literature presented enhancements in FIC, but few of them adopted the traditional fractal image model on the audio signal as shown in Section 6. This limitation is due to several obstacles that face the fractal image coding and thus made the FIC unpractical. In addition, there is the uncertainty of finding self-similarity in audio signals using the traditional fractal coding and the large size of the audio signal in comparison to images [6, 9].
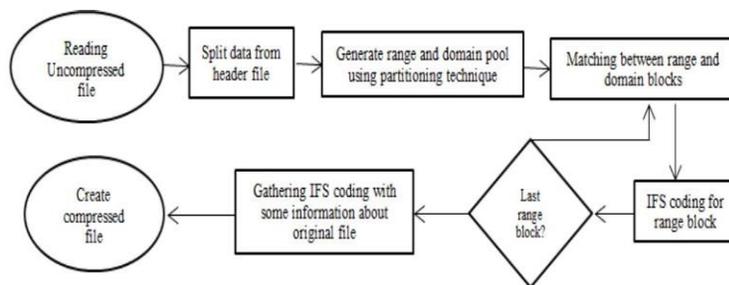

Fig. 1: *Fractal Encoding*

However, several techniques were adopted along with fractal coding to optimize the encoding time in the audio domain.

3 FRACTAL DOMAINS

Fractal domain means the media that is used to apply FC on. Generally, there are two main domains that should be considered when mentioning on FC in compression: image and audio. The literature showed that the fractal theory was firstly implemented on images by Fisher. The reason for choosing images was because the images exhibit a level of geometric feature. The gray image was a type of the images that were adopted to evaluate the efficiency of applying the

fractal theory. These images are two-dimensional M*N and uncompressed formatting matrix in which each pixel treated as
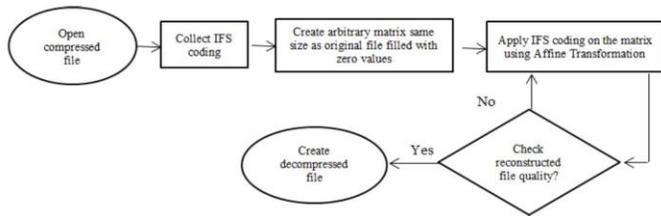

Fig. 2: *Fractal Decoding*

a point with x and y coordinates. The blocks which are used in these experiments were of two dimensions with 2×2, 4×4, 16×16 pixels. Then several studies later used color images with 24-bit and results are investigated to show the effect of the FIC on it [10, 11]. The audio signal is adopted later by researchers and used with fractal theory. The reason for this adaptation was identical in audio and image data and the implementation on audio signal could produce the same impact. However, the effect is variant in both kinds of data because the Human Visual System (HVS) and the Human Auditory System (HAS) are different [12]. The audio signal that is utilized in literature was uncompressed, one dimension signal with different sampling rate. The data is treated as a sequence of samples each one with 8-bit. The range and domain blocks also represent in 1-D with a different number of samples. A thorough investigation is required to check the ability to enhance the performance of the fractal audio compression.

3.1 Fractal Coding Challenges
There are several common issues in the implementation of fractal coding in both image and audio files. These issues were considered challenges in adopting FC together with the popular compression technique nowadays. These challenges are motivation for further research in both domains and can be summarized as [4]:
  a) Generating range and domain blocks using different partition methods.
  b) Matching process between range-domain blocks in order to find the best similarity between then using measurement to locate the minimum distortion.
  c) Reducing the encoding time by adopting speeding up techniques to minimize the time required.
  d) Shrinking the domain pool to reduce the computation in the matching process.

3.2 Fractal Coding Enhancements
Several ways have been suggested recently to solve a aforementioned issues in the FC model. The adaptation of various speeding up techniques was found more in images than audio domains. These developments can be classified mainly into these categories:
a) Optimization of pre-matching process
Searching or matching process is considered as the core of the fractal coding technique in which each range block matches with all blocks in the domain pool [6, 13]. This process is a time-consuming process. Many techniques were proposed to reduce the matching process and reduce the number of the range and domain block as well. Partitioning, classification, and clustering are the most techniques used at

this point. These techniques are considered as a pre-processing technique to filter out the domain blocks before the start in the matching process.
b) Parallel processing
Another way to reduce the large encoding time associated with FC is the parallel implementation. The development of the parallel computer architecture of the computational was the motivation to utilize this feature in accelerating the expensive complexity and then the efficiency of FC. Several studies were proposed different techniques of parallel computing on FIC ranging from complexity reduction, load balance and data partitioning depending on the proposed algorithm and hardware platforms. However, interest readers can follow [14] for more details about parallel algorithms in Fractal Image Compression.
c) Neural network
Soft computing methods are generally used to solve the problems that cannot be solved by traditional ones or that ones that take a long time. The large FC encoding time can be optimized using unconventional methods. Neural network and genetic algorithm were two of the nominated methods to settle consuming time issues. Several researches were proposed in this sense with different level of performances. In the last decades, FIC was the target of the researchers for adopting neural network and genetic algorithms to enhance efficiency. The analysis of the proposed FIC methods presented in [9-11] show that the performance of adopting this type of techniques with FIC in term of compression ratio is lower in comparison to the common method.

4 FRACTAL IMAGE COMPRESSION
The interest in FIC belongs to 1988 when Barnsley applied IFS to images for compression. Several methods were adopted since 2000. Truong et al. [15] proposed an algorithm to reduce the redundant calculation of the inner product in the fractal coding method. The inner product is the important part in computing the Mean Square Error (MSE) between range-domain in matching processes with the eight symmetry transformations. The proposed algorithm adopted the developed Discreet Cosine Transform which is called fast DCT presented in [16] to minimize the computational cost of DCT for every domain and range block. Wu [17] proposed a method of using regional search instead of whole image search. This method reduced the encoding time depending on the concept that the particular block has a high similarity to the blocks around and thus the time for matching will be minimized. This method minimized the time comparing to the conventional FIC. Tong and Pi [18] presented a distinguished performance for the fractal coding by suggesting an adaptive search based on an efficient and simple condition for blocks similarity with a low reduction in compression quality. This condition depends on the standard deviation of the domain and range blocks as a filter for the largely nominated domain blocks. In addition, they replaced the conventional affine parameter, luminance offset with the range block mean. Wu et al. [19] proposed a classification based on block variance. This classification reduces the consuming time of the fractal encoding process up to 480 times in comparison with the traditional one with a decrease in quality around 0.3 dB. This reduction is because of the fact that each range blocks matches with domain blocks within the same class. In addition, they used Partial Distance Search (PDS) which was proposed in [20] with simplified of the eight domain block transformations.
Geroge [21] presented an improvement for speeding up the

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matching process for FIC using moments indexing block and stopping condition. A further suggestion to increase the compression ratio and speeding is presented by the author through applying the additional type of filtering and partitioning schema. This technique speeds up the encoding time 10 times without significant changes in the image quality. Wu et al. [18] presented an enhancement to the search algorithm by proposing three methods: domain Intelligent Classification Algorithm (ICA), De-Redundancy Method (DRM) and Search Number Adaptive Control (SNAC). ICA is used to group the domain block with similar STD, DRM eliminates the domain blocks from domain pool which have very similar STD and SNAC ensures that range block with higher STD value matches with large domain blocks. Speeding up fractal colored image compression is proposed by Al-Hilo and George [22]. They adopt (Y, U, V) component instead of (R, G, B) with 24-bits/pixel resolution to increase the compression rate and moment features as a descriptor for range and domain blocks to speeding up the fractal encoding process. The presented speed is about 96% higher compared with traditional FIC. Another classification is produced by Kovacs [23] using two parameters which are: Approximate First Derivative (AFD) and Normalized Root Mean Square Error (NRMS). These parameters are used as a similarity measure between image blocks. George and Al-Hilo [24] presented an enhancement to the previous method proposed in [22], in which the compression ratio is increased by 3% by using DPCM and shift coding for encoding the range mean and scale parameters. In addition, this method decreases encoding time by 66% and enhances the PSNR at around 5.3%. George and Al-Hilo [25] also proposed a speed up method in which it reduced the number of symmetry transformation of the domain block from 8 to 1 using first-order centralized moments with the predictor. This predictor gives the required block transform to get the best range-domain matching and thus the encoding time is reduced. This method show speed up encoding process around 7 times in comparison with conventional method with preserving compression ratio and PSNR. Wang et al. [26] presented a fast FC approach by introduces correlation information feature to make the range-domain block matching near neighbor in the space. This feature results in a better result in term of reconstructed image quality with preserving the encoding time and compression ratio equal to other fast fractal coding studies. Hasan and Wu [27] proposed Adaptive Fractal Image Compression algorithm AFIC based on several techniques to minimize the complexity of the matching process. These techniques are Adaptive Quadtree Partitioning Technique (AQPT), Zero Mean Intensity Level (ZMIL), Reducing the Domain Image Size (RDIS), Range Exclusion (RE) and Variance Domain Selection (VDS). These techniques work together to increase the compression ratio and decrease the encoding time at the same time. This algorithm showed minimize in time in the expense of a decrease in reconstructed image quality in comparison with several related studies. Wang and Zheng [28] proposed a new FIC schema in which the Absolute value of Pearson's Correlation Coefficient (APCC) is used to classify the range and domain block. In addition, they sorted the domain blocks into sets according to the APCC to speed up the matching process between range and domain blocks. Fast fractal encoding algorithm based on Standard Deviation (STD) and Discrete Cosine Transform (DCT) are suggested by Wang et al. [6] to limit the search in the domain pool. They also used Auxiliary Encoding Algorithm

(AEA) to improve the quality of the retrieved image when the range block size is large. They compared their proposed algorithm with the full search FIC to check the algorithm performance. Pearson's correlation coefficient was also adopted in 2015 with the FIC in a method by Valarmathi et al. [13] to classify the domain blocks into three classes. In addition, the iteration-free method proposed by [29] is employed in this method. This method is applied to grayscale images. Jaferzadeh et al. [30] proposed an approach based on local binary features, intelligent STD threshold, and Humming distance techniques. This approach decreases the FIC encoding time comparing with full search method and decays in PSNR value of the reconstructed image. Dan Liu et al. [31] in their paper reviewed different methods used for compression of fractal images using parallel approaches. This parallel approach was introduced because of the high coding cost of this method. The major concerns discussed on the paper were load balancing, granularity, complexity reduction and data partitioning. Since the existing parallel processors were not reliable with the assumptions made in the past literatures, there is a need to improve the existing parallel hardware. These parallel processors will lack the primary memory to store the compressed as well as the incompressed image. Since the decoding algorithm was found to be the fastest in multiple cases, the advantages of the parallel fractal image decoding are not extremely valuable for the coding algorithm. D. Sophin Seeli et al. [32] analyzed the present fractal image compression techniques that achieve less computational time and expanded compression ratio. These techniques use various optimization methods for locating the ideal matching blocks. These FIC techniques were investigated in regard to their encoding time, compression ratio and Peak Signal-to-Noise Ratio (PSNR). They presented a comparative data by executing these FIC techniques for the above mentioned parameters. They concluded that improvements are warranted in these FIC techniques to obtain better compression ratios. Also a new and more powerful FIC method is required from past to achieve higher compression ratio. They found that the most prestigious technique gave higher compression ratio than the discussed techniques in their paper. Joshi [33] presented ERB and RDPS methods to alter the encoding time of FIC. The RDPS method focused only on reducing the time during encoding process while the ERB method focused majorly on the expansion of compression ratio with minor reduction in the encoding time. Later, they combined these two methods to obtain the advantages of both the methods. They found comprehensive results as the compression ratio expanded to double than that of the existing work with minimum loss in the quality of the image. They recommended that the affine parameters of these methods changes with image quality estimation such as MSE and SSIM. The image quality upgrades as the parameters expand and vice-versa. The proposed system is faster and has higher compression ratio with minimal loss in the image quality. They suggested that neighbor contrast and skewness might also be used in future for further improvements. Kominek [34] recommended the use of fast encoding for improvement in the fractal image compression techniques. They found that the advanced methods are almost five to six times faster than the older methods. Initially he discussed the conventional problems and the speed factors. The proposed fast FIC algorithm is an important step towards achieving better results. Since the full quad tree deterioration is used in

their work, hence a difference in the partitioning structures must be done, especially for HV partitioning. He suggested refining the domain pool filters. A hybrid algorithm was recommended combining the FFIC with spiral search and augmentation of the bilinear fractal transforms to achieve better results. Jaseel et al. [35] proposed the use of DBSCAN algorithm to accommodate a picture using fractal compression approach. They decreased the successive search through the picture to its neighbors which inturn reduces the encoding time. This process decompresses the pictures quickly. On contrary to the conventional FIC techniques, the computational time was reduced comprehensively. Since the web has an exceptionally large database of images, maintaining, storage and transfer of data requires more cost and computation time, hence the image compression acts as an important tool to reduce these complexities in a far easy manner. Their proposed work groups images in a square piece by piece rather than checking in pixel by pixel. Using the RGB values independently, this method groups the shaded images rapidly and interprets them easily. This method is far more advantageous for an image in image concept which is quite common these days. Nodehi et al. [36] proposed a two-phase algorithm to decrease the MSE computations while performing the fractal image compression. Initially they segregated the image pieces into three different classes by using the DCT coefficients as indicated by image squares edge property. Using the DCT transformation method, these squares of the image could be transformed to the recurrence domain for spatial domain. Using the arrangements of the DCT coefficients on the upper left and lower right of the images pieces, one can easily explore the class of the image square. In the second phase, reasonable domain pieces are located

enhances the quality of the reproduced image during compression. Even to little annoyance, the key present in the encryption provides extensive key space with higher affectability. Additionally, the dispersion procedure and stream figure encryption used in their work causes problem in the plaintext. It achieves high plain affectability and provides immunity to different plaintext assaults. A total of 2272 key space with 10 x 10 Julia set is used in the encryption procedure. They conducted a point wise investigation of the Julia set and found that as the value of K fits within 8 to 10, the affectability of the image for both plaintext and key is high. A respectable arbitrariness was found in case of the ciphertext which was tested for sp800-22 test suite. Later they tested their method for decoding time and encryption utilization for different image sets. Their result showed that the compression procedure included less than 15% of encryption procedure which implies that the compression process is not delayed by the encryption operation.

5 CLASSIFICATION OF FIC TECHNIQUES

Fractals are the images particular shape or geometry which is subjected to some mathematical equations. Fractal image can be constructed using set of transformations which can be applied on the image iteratively. The set of mathematical iterations are called Iterated function system. In fractal image compression iterated function system is widely used to obtain the better results. Due to heavy computation and processing use of Iterated function system is quiet complex. To reduce the complexity of processing the idea of partitioned iterated function system is incorporated in fractal image compression. In partitioned iterated function system (PIFS), image is subdivided into non-overlapping range blocks. The selection of range block is totally depending upon the self-similar

TABLE 1. *ANALYSIS OF DIFFERENT FIC METHODS*

S.No.	Literatures	Methods	Correctness criteria
1.	[50]	Julia set and fractal dictionary	Compression performance, key space analysis, sensitivity analysis
2.	[51]	Wavelet transform, Quadtree encoding	Encoding time, decoding time, mean square error, peak signal-to-noise ratio, MAXERR, L2RAT
3.	[52]	Quadtree and embedded block coding optimization truncation	Compression ratio, peak signal-to-noise ratio
4.	[53]	Kernel density estimation function	Image retrieval rate and speed
5.	[54]	Stopping search, YUV component	Peak signal-to-noise ratio, encoding time
6.	[55]	Image annotations	Texture, color, accuracy measurement
7.	[56]	Edge-based search using neighborhood method	Encoding time, mean square between errors, decay
8.	[57]	Particle swarm optimization	Peak signal-to-noise ratio, encoding time
9.	[58]	Fast encoding algorithm	Encoding time, peak signal-to-noise ratio
10.	[59]	Fractal image compression using affine transformations	Compression ratio and peak signal-to-noise ratio

using the ICA algorithm and utilizing the initial steps for further processing. The conventional FIC algorithm lags behind the MSE calculations in the Boolean image by around 500 times which makes it quite noticeable. On the other hand, the PSNR is only around 0.41 as that of the conventional FIC algorithm and hence not much worthy. For finding the least optima in the entire image, ICA algorithm works really well. Sun et al. [37] proposed a new image compression-encryption method which utilizes Julia set and a fractal word reference. This fractal word reference encoding reduces the computational time and

properties among the range blocks [38], [39], [40]. Similarly, the blocks which are larger than the range blocks are chosen as domain blocks. On the basis of self-similar property each range block then mapped with the appropriate domain block. Mapping among range and domain blocks requires lots of computation time hence the use of affine transformation is required for appropriate mapping and reducing computation time. Affine transformations are combined transformation which involves translation, rotations and scaling of the image. In fractal image compression the decoding phase is quite

simple. Fractal image compression can be classified as follows by considering domain-range pool self-similarity criteria:

a. Domain-Based Classification: The process of Fractal image compression has been found to be irregular in both time of execution and operations of algorithms. The time required for encoding is larger than the time required for the process of decoding. In order to compress an image appropriately the chosen domain block must be matched with the correct range block. Thus, "no-search algorithm" was suggested to minimize time required for searching the particular domain block from the domain pool. Although the time for encoding and searching has been minimize but the quality has been degraded. Domain blocks are considered to be static, hence it is suggested in the algorithm to introduce dynamic domain block in order to improve the quality as well as reduce encoding time [41], [42].

b. Dynamic-Based Method: The search for the domain block in domain pool is static and incorporates computational complexity. In order to enhance quality and to minimize the computation time dynamic search for domain-range similarity has been suggested. Thus, to search domain block dynamically, fractal dimension of the range block has been used [43], [44], [45]. Local Fractal Dimension-Based Search: To search the similarity between two or more than two fractals, fractal dimension measure is widely used. This measure

ensures how compactly fractals can be fitted in a given image. Fractal dimensions can be obtained by computing fractal dimension of range block, after that search for the domain block in the domain pool. To minimize the computational time, other methods have been suggested [46], [47].

c. Height-Balanced Tree-Based Search: Height-balanced method is used for stable time complexity because insertion, deletion, searches, rotation becomes stable. In height-balanced method, balance factor is computed which is the difference between depth of left subtree and right subtree. During insertion and deletion operation, balance factor is computed in interval to maintain the time complexity. Instead of having many height-balanced search methods, AVL is most suitable in terms of time complexity and stability. Quadtree technique is incorporated to enhance the performance of encoding technique as proposed in [48], [49].

6 ANALYSIS ON FRACTAL ENCODING TECHNIQUES

On the basis of analysis, the authors have formulated a table using the different FIC techniques used along with their criteria in different literatures.

TABLE 2. COMPARISON OF PSNR VALUES AND ENCODING

S.No.	Literatures	PSNR (db)	Encoding time (sec)	Compression ratio
1.	[50]	31.523	0.244	-
2.	[51]	43.26	54.58	-
3.	[52]	31.19	23.48	19.94
4.	[54]	32.39	132.11	9.64
5.	[56]	32.41	61.23	-
6.	[57]	35.94	934.32	-
7.	[58]	28.61	10.79	-
8.	[59]	29.03	202.84	93.05
9.	[60]	31.12	49.24	-

7 DISCUSSIONS

As noticed in the literature review, most of the studies are dedicated to use fractal coding as a compressor with images, since fractal coding was firstly and mainly studied and introduced with the images. From a large number of studies that were proposed on fractal image coding, it has been demonstrated that fractal coding can successively apply with acceptable reconstruction image result. The future aspect of fractals seems to focus on adopting other techniques or transform to enhance the performance of the FIC. Built upon the success of FIC, this method has also been practiced in fractal audio coding which suggests the possibility of adopting FC in audio signals. A limited number of studies has been presented in the literature to investigate the efficiency of the FAC. Pre-processing can play a promising role in terms of improvement. A preprocessing step can be used to break the continuity in audio sequences, which may provide a way of compensating for the shortcomings of fractal systems. In fractal image coding, many applications have been applied with FIC as wavelets and DCT. We expect that the same concept may be applicable in fractal audio coding and could be equally successful. Concerning audio data, classification could accelerate the compression ratio and speed up FAC, although, classification is a more general topic that can be addressed from variant perspectives.

8 CONCLUSION

A review on fractal image and audio compression, and their enhancing techniques have been presented in this study. It is obvious that interest is directed to fractal image more than the audio domain. The adaptation of fractal image coding is due to several reasons and the natural similarity in images is one of them. FIC produces high compression ratio in comparison to other image compression techniques. On the other hand, this study reveals the limitation of published articles in term of fractal coding in audio signals. The earlier studies in this field exhibit the ability to get an acceptable result by adopting fractal theory with audio. Further research is required in the area of fractal audio compression specifically and in fractal image compression generally in order to make these two techniques stand side by side with the counterpart.

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