Performance Assessment of Fractal Coding on Remote Sensing Images with Different Imaging Modalities

D.Sophin Seeli, M.K.Jeyakumar

Abstract - Image compression coders can be lossy or lossless. Fractal image compression is a lossy image compression technique to achieve high level of compression while preserving the quality of the decompressed image close to that of the original image. The method relies on the fact that in certain images, parts of the image resemble other parts of the same image. The compression procedure consists of dividing the image into range blocks and domain blocks and then it takes a range block and matches it with the domain block. It is a new technique in image compression field based on Affine contractive transforms. In the present work the fractal coding techniques are applied for the compression of remotely sensed imageries. Also the results are compared with various imaging modalities and the parameters that affect fractal image compression are studied. The comparison results that fractal image compression techniques are found more effective for compressing remote sensing images.

***Index Terms** - Fractal, encoding, self-similarity, affine transformation, quad tree partitioning*

I. INTRODUCTION

Fractal geometry provides a mathematical model for complex objects found in nature such as mountains, and clouds. These objects are described by traditional Euclidean geometry. Self-similarity is an essential property of fractal in nature and may be quantified by fractal dimension. The JPEG algorithm is widely used in all areas of image storage and processing, from digital cameras through to photographic archives and libraries. For most purposes the JPEG algorithm is highly satisfactory in that it is fast and efficient, allowing a choice between moderate compression ratio with small loss of quality, through to large compression ratio with a more noticeable loss of quality.

Other image compression techniques are available, one such approach is based upon Fractal Image Compression (FIC) [1][2]. This technique seeks to exploit affine redundancy that is present in typical images in order to achieve high compression ratios, generally maintaining good image quality with resolution independence. The main drawback of FIC however is that there is a very high computational cost associated with the encoding phase [3]. Although the encoding is expensive, the decoding is fast and straightforward, and allows smooth images to be recovered at all levels of resolution. Furthermore, the compression ratios achieved can be very high in FIC [4].

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A. Related Work

JPEG and other DCT based compression techniques [20] have been employed in many space missions. Bo li et al. [21] proposed a 2-D Oriented Wavelet Transform for remote sensing image compression, which performs integrated oriented transform in arbitrary direction and achieve a significant transform coding gain. Yu Jie et al.[22] proposed the compression method uses the wavelet-transformation to create the similarity between sub-bands of an image, and the fractal algorithm is exploited to code for adjacent high-frequency bands with similarity character. D.Napolian et al.[23] presented remote sensing image compression technique based on wavelet transform.

II. FRACTAL COMPRESSION

A. Fractal

Fractal is a structure that is made up of similar forms and patterns that occur in many different sizes. The term fractal was first used by Benoit Mandelbrot [8] to describe repeating patterns that he observed occurring in many different structures. These patterns appeared very similar in form at any size although with rotation, scale or flipping. Mandelbrot also discovered that these fractals could be described in mathematical terms. In fractal theory, the formula needed to create a part of the structure can be used to build the entire structure.

B. Self Similarity in Image

Figure 1-a shows sample regions of Lena which are similar at different scales: a portion of her shoulder overlaps a region that is almost identical, and a portion of the reflection of that in the mirror is similar (after transformation) to a part of her hat. The image will be formed of copies of properly transformed parts of itself. This means that the image we encode as a set of transformations will not be an identical copy of the original image but rather an approximation of it. Experimental results suggest that most images that one would expect to "see" can be compressed by taking advantage of this type of self-similarity; for example, images of trees, faces, houses, mountains, clouds, etc[5][6].

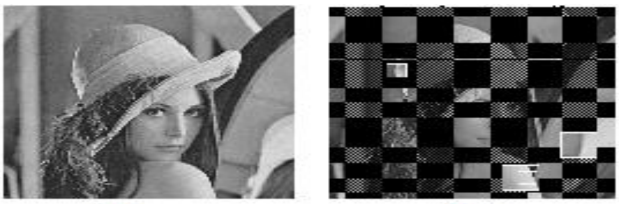
(a) (b)

Figure 1. The original Lena Image and its self similar portions

C. Contractive Transformations

A transformation w is said to be contractive if for any two points P1, P2, and the distance

$$d\,(w(P1),w(P2)) < sd(P1,\, P2)\ ,$$

for some s < 1, where d = distance. This formula says the application of a contractive map always brings points closer together.

The Contractive Mapping Fixed Point Theorem says: if a transformation is contractive then when applied repeatedly starting with any initial point, we converge to a unique fixed point. If X is a complete metric space and W: X->X is contractive, then W has a unique fixed point W.

D. Affine transformations

The transformations having the limitation that they must be contractive, that is, a given transformation applied to any two points in the input image must bring them closer. The transformation can have any form. The transformation form is shown in equation (1)[2].

$$W_i\begin{vmatrix} x \\ y \end{vmatrix} = \begin{vmatrix} a_i b_i \\ c_i d_i \end{vmatrix}\begin{vmatrix} x \\ y \end{vmatrix} + \begin{vmatrix} e_i \\ f_i \end{vmatrix}, \qquad \ldots\ldots.(1)$$

Where x,y – coordinates;

a,b,c,d,e,f – coefficients,

This equation is ample to generate transformations called *affine transformations* of the plane. Each can skew, stretch, rotate, scale and translate an input image. The eight affine transformations considered are as illustrated in figure 2.

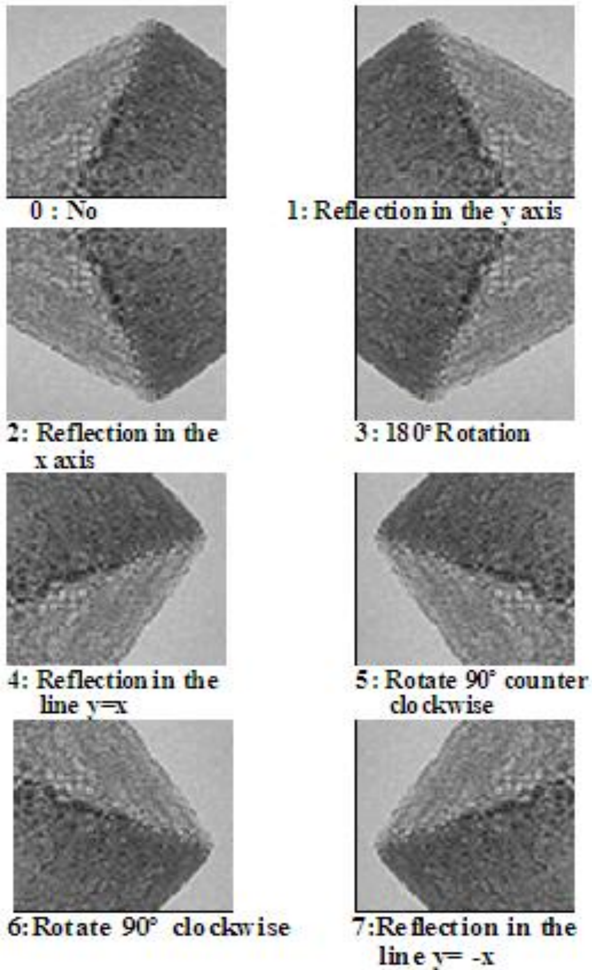

Figure 2: Affine Transformations

III. PIFS METHOD OF FRACTAL IMAGE COMPRESSION

The task of compressing an image using PIFS [9] method includes three important phases:

1. Partition the image and find transformations for each partitioned part;
2. Encoding (compressing) the image.
3. Decoding (decompressing) the image.

A. Partitioning Images

In this FIC, quadtree method is applied to partition images because of its orderliness, simplicity, and efficiency.

Quadtree Partitioning

Quadtree is an image structure [7] and most common method of partitioning. Beginning with the original image, square pixel blocks are broken down into quadrants in a recursive tree structure. The partitioning is terminated when a particular condition is satisfied. The recursive definition about quadtrees is: A quadtree is a finite set consisting of several nodes which are either empty or consist of a root and at most four non-overlapping quadtrees.

To obtain a quadtree of an image, the procedure is: Suppose we have a 2^n x 2^n binary image in which points with value "1" represent the "feature" points as black ones and points with value "0" represent background points as white ones. First, the whole image is served as the root node. If the node does not consist of all "1" value or all "0" value points, it is called a gray node and needs further decomposition. As the first step, divide the whole image into four 2^{n-1} x 2^{n-1} sub-image, then decide if further decomposition is needed. The sub-images are not only son nodes of the whole image but also the root nodes of its own. If one node consists of all "1" value points or all "0" value points, and then stop decomposing the node; if the node has both "1" value points and "0" value points, and then decompose it again until all sub-images consist of points with the same values. This kind of hierarchical quadtree occupies huge amounts of storage.

Gargantini and Lauzon et al. introduced one coding method [7] for linear quadtrees, called "Two Dimensional Run-Encoding", takes advantage of compactness. The quadtree structure began to be used in image processing and image encoding areas [12][13][14]. As the first step, the image is partitioned by some collection of ranges Ri. The ways of partitioning the image into domains and ranges are both quadtree method. The sets Ri and Di, determine s_i and o_i as well as a_i, b_i, c_i, d_i, e_i, and f_i using equation (1).

Determining Parameters

Once the image is partitioned, it is needed to determine the transformation coefficients for each partition. Given two squares containing n pixels intensities, $a1$, ….., an (from D_i) and $b1$, …, bn (from R_i), then calculate s and o to minimize the quantity of R in equation (2)

$$R = \sum_{i=1}^{n} (s.a_i + o - b_i)^2 \qquad \ldots\ldots.(2)$$

This gives contrast and brightness setting that makes the affinely transformed a_i values have the least squared distance from the bi values. The minimum of R occurs when the partial derivatives with respect to s and o are zero, which occurs when the equations (3) and (4) are satisfied.

$$s=[\,n^2(\sum_{i=1}^{n} a_i b_i) - (\sum_{i=1}^{n} a_i)(\sum_{i=1}^{n} b_i)]/[n^2\sum_{i=1}^{n} a_i^2 - (\sum_{i=1}^{n} a_i)^2] \ \ldots.(3)$$

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$$o=[\sum_{i=1}^{n} b_i - s\sum_{i=1}^{n} a_i]/n^2 \qquad \text{........(4)}$$

B. Encoding (Compressing) Algorithm

The fractal image compression shares many features in common with fractal generating algorithms [15]. The basis for the encoding procedure is: an image is partitioned into parts that can be approximated by other parts after some scaling operations. The following example suggests how the Fractal Encoding can be done. Suppose that we are dealing with a 128 x 128 image in which each pixel can be one of 256 levels of gray. We called this picture Range Image. We then reduce by averaging (down sampling and lowpass-filtering) the original image to 64 x 64. We called this new image Domain Image. We then partitioned both images into blocks 4 x 4 pixels (Figure 3)

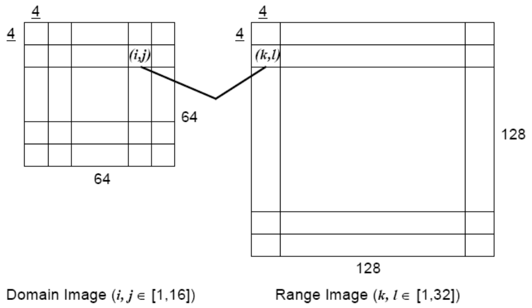

Figure 3: Partition of Range and Domain

We perform the affine transformation to each block as:

$$(D_{ij}) = \alpha D_{ij} + t_o$$

Where α = [0,1], $\alpha \in \Re$ and t_o =[-255, 255], $t_o \in z$. In this case find linear transformations of Domain Block to arrive to the best approximation of a given Range Block. Each Domain Block is transformed and then compared to each Range Block $R_{k,l}$. The exact transformation on each domain block is the determination of α and t_o is found minimizing in equation (5)

$$\min \sum_{m,n} (R_{k,l})_{m,n} - (\Gamma(D_{ij}))_{m,n} \qquad \text{.....(5)}$$

With respect to α and t_o which are shown in equation (6) and in (7)

$$\alpha = \frac{N_S^2 \sum_{m,n}(D_{i,j})_{m,n}(R_{k,l})_{m,n} - \left(\sum_{m,n}(D_{i,j})_{m,n}\right)\left(\sum_{m,n}(R_{k,l})_{m,n}\right)}{N_S^2 \sum_{m,n}\left((D_{i,j})_{m,n}\right)^2 - \left(\sum_{m,n}(D_{i,j})_{m,n}\right)^2} \qquad \text{.....(6)}$$

$$t_o = \frac{(\sum_{m,n}(D_{i,j})_{m,n})^2 - \sum_{m,n}(R_{k,l})_{m,n})^2}{N_s^2 \sum_{m,n}((D_{i,j})_{m,n})^2 - (\sum_{m,n}(D_{i,j})_{m,n})^2} \qquad \text{.....(7)}$$

where m, n, N_s = 2 or 4 (size of blocks)

Each transformed domain block $\Gamma(D_{i,j})$ compared to each range block $R_{k,l}$ in order to find the closest domain block to each range block. This comparison is performed using the distortion measure equation (8).

$$d_{l_2}(\Gamma(D_{i,j}), R_{k,l}) = \sum_{m,n}((\Gamma(D_{i,j}) - (R_{k,l})_{m,n})^2 \qquad \text{....(8)}$$

Each distortion is stored and the minimum is chosen. The best transformed domain block for the current range block is assigned to that range block, i.e. the coordinates of the domain block are saved into the file describing the transformation. This is what is called the Fractal Code Book.

$$\Gamma(D_{i,j})_{best} \Rightarrow R_{k,l} \qquad \text{........(9)}$$

The result of the procedure is a set of transformations, which, when iterated from *any* initial image, possess a fixed point approximating the original image.

The steps of the encoding (compression) procedure are as follows:

1) Decide the parameters image name, image size, minimum partition exponent, maximum partition exponent and tolerance for fidelity for compressing.
2) Read the image to be compressed.
3) Process 'domains'

a) Scale the image by calculating the average values of each four-pixel group, then save the calculated values into an array 'domain'

b) Divide the image (in 'domain') into overlapping domains (16x16 or 8x8)

c) Divide each domain block into four quadrants and calculate the variance of each quadrant.

d) Classify the domains into 24 classes according to the order of the variances of the quadrants of the domain blocks. Record the position, the size and the class of the domain blocks in the corresponding class chain.

e) After processing the 16x16 domains, the procedure is repeated until you reach the smallest domains (4 x 4) as specified by the maximum partition exponent.

4) Record the parameters into the output file including image size, maximum partition, minimum partition exponents, and maximum and minimum values of the image.

5) Process 'ranges'

a) Partition the original image into 'ranges' according to the quadtree method. If the minimum partition is not reached, go ahead to continue the partition until the minimum partition is reached.

b) Classify the range according to the same rule as did for domains, i.e. 24 classes based on the order of the variances of the quadrants of the block.

c) Search the domain class chains to find the domain which matches the current range best by calculating the RMSE(Root Mean Square Error) between the domain and range as Y - AX + B (Y corresponds to the values in the range, X the values in the domain). Record the position and the rotating factor (if the domain has a different class than the ranges) of the domain with the smallest RMSE, and A and B.

d) Check

a) if the smallest RMSE is less or equal to the tolerance and

b) if the maximum partition is reached.

i. If both are 'Yes', go to (5);

ii. If a) is 'Yes' and b) is 'No', go to (5);

iii. If a) is 'No' and b) is 'Yes', go to (5);

iv. If both are 'No', put a bit '1' as a flag into the output file, then

v. Divide current range into 4 sub-ranges according to the quadtree method, then go to(2).

e) Write A, B, the rotating factor, the position of the domain with smallest RMSE, into the output compressed file.

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6) Calculate the compression rate: the number of bytes of the original image divided by the number of bytes in the output compressed file. The encoding algorithm includes the parameters the maximum depth, the minimum depth, the maximum allowable scaling factor s_{max}, the number of classes compared with a range and the maximum and minimum values of the image of the quadtree partition

An encoding of an image consists of the following data:

- The final quadtree partition of the image
- The scaling and offset values s_i and o_i for each range
- The symmetry operation (orientation) used to map the domain pixels onto the range pixels.

The flow chart for compression is shown in figure 4.

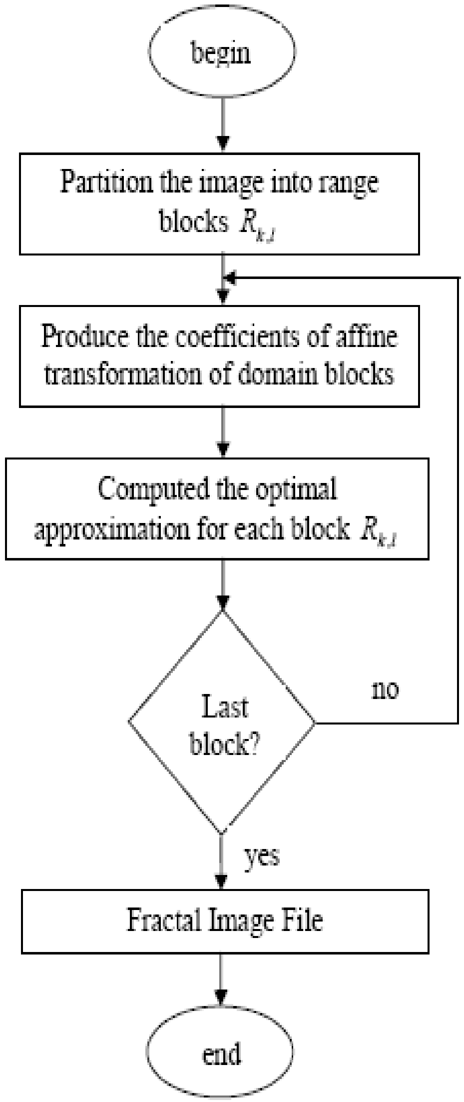

Figure 4: Flow chart for image compression

C. Decoding (Decompressing) Algorithm

Decoding an image consists of iterating *W* from any initial image. The quadtree partition is used to determine all the ranges in the image. For each range R_i, the domain D_i, which maps to it is shrunk by two in each dimension by averaging non-overlapping groups of 2 x 2 pixels. The shrunken domain pixel values are then multiplied by s_i, added to o_i, and placed in the location in the range determined by the orientation information. This constitutes a decoding iteration. The step is iterated until the fixed point is approximated, that is, until further iteration does not change the image or until the change is below some small threshold value. The reconstruction process of the original image consists on the applications of the transformations describe in the fractal code book iteratively to some initial image Ω_{init}, until the encoded image is retrieved back. The flow chart for decompression is shown in figure 5.

The transformation over the whole initial image can be described as follows:

$$\left.\begin{array}{l}\Omega_1 = \eta(\Omega_{init}) \\ \Omega_2 = \eta(\Omega_1) \\ \Omega_3 = \eta(\Omega_2) \\ \ldots\ldots\ldots\ldots \\ \Omega_n = \eta(\Omega_{n-1})\end{array}\right\} \qquad \ldots\ldots(10)$$

η can be expressed as two distinct transformations:

$$\eta = \Gamma(\Omega)\Psi(\Omega) \qquad \ldots\ldots(11)$$

$\Gamma(\Omega)$ represents the down sampling and low pass filtering of an image Ω to create a domain image e.g. reducing a 128x128 image to a 64x64 image. $\Psi(\Omega)$ represents the ensemble of the transformations defined by our mappings from the domain blocks in the domain image to the range blocks in the range image as recorded in the fractal.

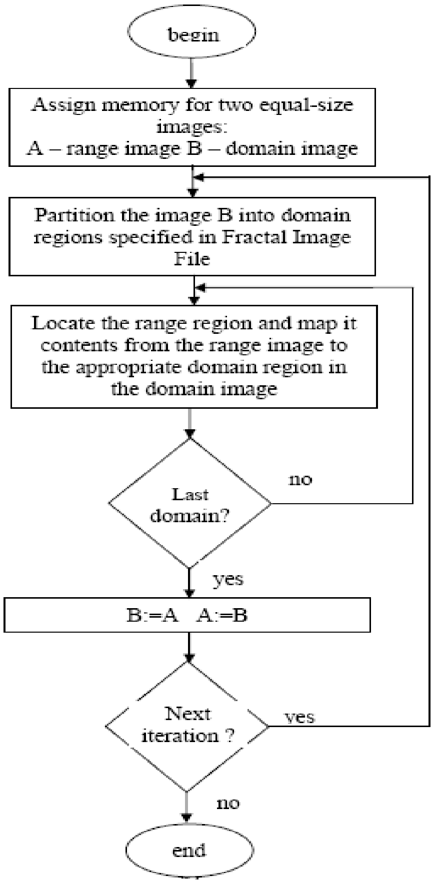

Figure 5: Flow chart for image decompression

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IV. IMPLEMENTATION AND EVALUATION

A number of quality measures have been defined [16] to determine the closeness of the degraded and original image fields. The pixel difference based measures [17] such as Mean square error and maximum Difference and correlation based measures such as structural correlation and Normalized correlation are measured. The quality measures are listed in Table-1.

Table 1: Quality Measures

Quality Measure	Equation
Mean Square Error	$1/MN\sum_{i=1}^{M}\sum_{j=1}^{N}(f(i,j)-f'(i,j)^2)$
Peak Signal-to-Noise Ratio	$20\log_{10}\left[\frac{N}{RMSE}\right]dB$
Average Difference(AD)	$\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(f(i,j)-f'(i,j))$
Maximum Difference (MD)	$\max(\lvert f(i,j)-f'(i,j)\rvert)$
Normalised Correlation (NK)	$\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(f(i,j).f'(i,j))}{\sum_{i=1}^{M}\sum_{j=1}^{N}f(i,j)^2}$
Mean Absolute Error (MAE)	$\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(\lvert f(i,j)-f'(i,j)\rvert)$
Normalised Absolute Error(NAE)	$\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\lvert f(i,j).f'(i,j)\rvert}{\sum_{i=1}^{M}\sum_{j=1}^{N}\lvert f(i,j)\rvert}$
Structural Correlation/Content (SC)	$\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}f(i,j)^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}f'(i,j)^2}$

V. RESULTS AND DISCUSSION

FIC analysis is made for five images each in X-ray (IMG1), mammogram (IMG2), ultrasound (IMG3), MRI images (IMG4), cartoon(IMG5), fingerprint(IMG6), iris(IMG7) and remote sensing(IMG8) grayscale images of size 256 x 256 using the MATLAB Software and the computation results are presented in Table-2 and in Table-3 The table presents the values of various measures that include quality constraints.

The compression ratio for the remote sensing images is the highest at 36.0 with the PSNR 23.75 and for the ultrasound images it is lowest.

- PSNR is most widely used objective image quality distortion measure. Larger PSNR indicate a smaller difference between the original and reconstructed image.
- Mean Square Error presents the deviation between the original and coded images. The effectiveness of the coder is optimized by having the minimum MSE at a particular compression.
- A lower value of Average difference guesses a cleaner image and indicates good quality image and is obtained with the remote sensing image and with the mammogram images as 0.0000371, 0.0000963 respectively. With iris images it is high as 0.0005473.
- Smaller value of Maximum Difference means that the image is good quality.
- Normalized correlative measures the similarity between two images and presents the closeness between the original and decoded images. This value tends to 1 if the difference between the images is zero and from the computed values it is observed that for remote images. FIC are highly correlated note original images and ultra sound images have fewer correlatives between the original and decoded images.
- The measure NAE is used to study the quality of appropriation of the images. Normalized absolute error is computed to find how far the decompressed image from the original image. Large value of the Normalized absolute error indicates poor quality.
- Structural correlation estimates the similarity of the structure of two signals. The structural content compares the total weight of the compressed image and original image, and its value tend to 1 indicate a better quality image and is close to remote images.

Evaluating the quality different modalities of images is a useful and complicated task. From the executed values shows that when FIC is applied the remote images the measures are close to the optimum values. The values deviates more for the other images because of high pixel variation.

VI. CONCLUSION

In this paper a successful implementation of a fractal coder for different imaging modalities are demonstrated. Fractal coders can perform very well in terms of bit rate and PSNR for satellite images. The most important feature of Fractal Decoding is the high image quality when zooming in/out on the decoded picture. Fractal images compression has the characteristics of high compression ratio, fast decoding and long coding time.

From the analysis carried out in the paper, the fractal coding techniques can be applied for achieving high compression ratios and better peak signal-to-noise ratio values for satellite images.

Table 2: Performance of Fractal Image Compression on various images

Images	MSE	AD	MD	NC	MAE	NAE	SC
IMG1	20.7077	0.0001315	63.3895	0.99858	2.6088	159.5115	1.0025
IMG2	10.3398	0.0000963	119.9834	0.99831	0.85939	146.6108	1.0022
IMG3	96.0713	0.0001814	153.9428	0.96224	3.4674	74.0392	1.0426
IMG4	58.0796	0.000176	124.6807	0.99288	3.0142	121.8616	1.0078
IMG5	79.4115	0.0002097	162.3586	0.99158	7.4518	174.1532	1.0094
IMG6	88.2996	0.000334	115.8027	0.98618	12.6381	156.9528	1.0151
IMG7	79.1986	0.0005473	98.4086	0.97112	4.01223	135.7890	1.0540
IMG8	10.3374	0.0000371	159.6891	0.99679	1.4632	145.5843	1.0020

Table 3: Compression Ratio and PSNR values of images

Image	Block size	Image size	Compression ratio	PSNR
IMG1	4x4	256x256	10.55	21.999
IMG2	4x4	256x256	9.1217	37.983
IMG3	4x4	256x256	0.7175	27.544
IMG4	4x4	256x256	10.76	27.17
IMG5	4x4	256x256	15.07	22.61
IMG6	4x4	256x256	19.23	19.97
IMG7	4x4	256x256	4.31	38.59
IMG8	4x4	256x256	33.76	23.95

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Further improvement can be attained by considering the different dimensions of the range blocks and optimizing number of iterations. This type of compression can be applied in satellite band images, where we need to focus on image details, and in Surveillance Systems, when trying to get a clear picture of the intruder.

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