ISSN : 2231-0711

IJCSET |September 2011 | Vol 1, Issue 8, 499-502

Performance of Kick-Out Condition Based Speedup Techniques in Fractal Image Compression

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***Abstract*— Fractal Image compression is a ground-breaking image compression technique in the area of image processing. This technique is based on fractals rather than pixels. It is advantageous in compression ratio, decompression speed, bit-rate and resolution independence. But in conjunction with above advantages, the encoding phase of this technique consumes huge time, which is a major drawback and restricts its area of applications. A lot of theories have been proposed to overcome this limitation. This paper represents a study of Kick-Out Condition based speedup techniques in fractal image compression.**

***Index Terms*—Fractal image coding, zero contrast, conventional full search, kick-out rule, DCT inner product, normalized one-norm.**

I. Introduction

Fractal theory was proposed by Barnsley and first realized by Jacquin [2] based on a partitioned iterated function system. Fractal image compression may provide an image with higher image quality & compression ratio (CR). Jacquin proposed the first practical fractal image compression method, which relies on the assumption that image redundancy could be efficiently exploited through self-transformability on a block-wise basis.

The problem with fractal coding is the high computational complexity in its encoding process. In this process most of the encoding time is spent in searching the best matched domain block from a large domain pool for an input range block. To solve this problem, some efficient fractal encoding methods [3], [6–10] have been developed. Bani-Eqbal [12] proposed a tree search method, in which an incremental procedure is used to bind the domain block pixels, and then arranged the domain blocks in a tree structure to direct the search. Tong [11], proposed a fast fractal image encoding method based on an adaptive search algorithm to reduce the computational complexity. Also partition based approach was proposed [4-5, 13-14]. The above techniques can reduce the required computation at the cost of requirement of additional memory and degradation of the reconstructed image quality when compared with the full search method. DCT inner product method was proposed by Truong [15]. In order to reduce computation time, Discrete Cosine Transform (DCT) reduces the number of computations of the inner product from eight to two. The other inner products can be obtained by a proper arrangement of these two inner products. That means, this method reduces the number of isometry transformations from eight to two. The DCT inner product method saves computation time and provides similar decoded image quality as in the full search method.

Further, a computation-efficient method presented by Lai-Lam-Siu [16] in which fractal image coding based on kick-out and zero contrast condition was proposed. This method has the same decoded image quality as in the full search method. In this method kick-out condition can decide efficiently that which domain block is the best matched with a range block, and hence too much computation can be reduced. With zero contrast condition, the computational complexity is further reduced.

Also, another fractal image encoding method was proposed by Hsiu et al's [17] using normalized one- norm and kick-out condition. In this method, unmatched domain blocks can discard at earlier stage in the process of finding the best matched domain block. Its decoded image quality is similar as in the full search method.

This paper is organized as follows. In Section II We briefly describe the fundamentals of the fractal image compression. In Section III we discuss about the kick-out condition based techniques. Comparison of these kick-out condition based techniques presented in section IV & in section V some concluding notes are given.

II. Fractal Image Compression

In fractal image compression, compressed image is the function of contractive transforms which are composed of the union of a number of affine mappings on the whole image, known as iterated function system. Barsnley has proposed a special form of the Contractive Mapping Transform called the College Theorem which provides distance between the image to be encoded and the fixed point of a transform, in terms of the distance between the transformed image and the image itself. This distance is known as college error and this should be small. In Jacquin's method the image is partitioned in sub images called as 'Range blocks' and Partitioned iterated functions are applied on sub-images, rather than the entire image. Locating the range blocks on their respective position in image itself forms the entire image. Temporary images used to form range blocks are known as domain blocks.

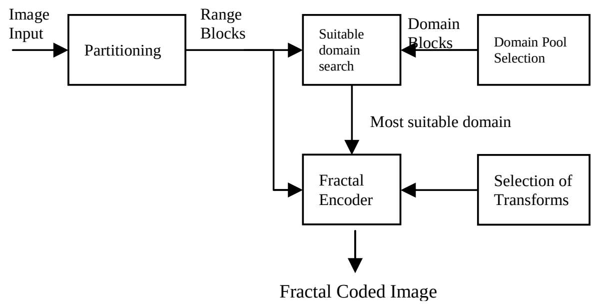

Fig 1: Block Diagram of Fractal Image Encoding Process

The process of fractal image compression has four steps of decision making. The first decision step is to be selecting the type of image partition method to form the range blocks. The second step of decision making is Domain pool selection. The Third step of decision making is transformation selection. These transforms are applied to domain blocks to form range blocks. The partition scheme used and the type of domain pool used affect the choice of transforms. Fourth step of fractal encoding process is searching of the most suitable domain block to encode any particular range block. This step of fractal image compression is computationally time consuming. Figure 1 [18] shows the whole process of fractal image encoding.

In fractal image compression method, the input image f is partitioned into two types of block units:

The nonoverlapping range blocks of size $N = n \times n$ and the overlapping domain blocks of size $M = m \times m$. suppose the number of range blocks is N_R and the number of domain blocks is N_D.

The image f can be expressed by,

$$f = \bigcup_{i=1}^{N_R} R_i \quad (1)$$

The size of a domain block is generally four times that of a range block, i.e. $M = 4N = 2n \times 2n$. To encode a range block R, each domain block in the domain pool is scaled to the size of the range block. Each pixel value in the contracted domain block can be represented by the mean of the four neighbouring pixel values in the original domain block.

In suitable domain search part we look forward for compatibility between range images & domain images. For every range image a suitable domain range block is searched from domain pool.

For suitable domain search, a method was proposed by Jacquin [2] known as full search method. In this method to find the best matched domain block in the large domain pool for an input range block R, the following error term should be minimized.

$$E(R, D_i) = \|R - (sD_i + oI)\|^2 \quad (2)$$

where the symbol $\|.\|$ denotes the 2–norm operation, D_i is the contracted domain block, I represents the constant block, and s and o are the contrast and brightness offset parameters, respectively. The term $(sD_i + oI)$ is used to adjust the contrast and brightness of the block D_i. In order to determine the best matched domain block for an input range block, the eight isometric transformations consisting of four orientations and four reflections of each domain block must be considered.

For a given range block R and domain block D, the linear least squares method can be used to determine the contrast and brightness offset parameters. Then, the two parameters s and o can be computed by

$$s = \frac{\langle R - \bar{r}\, I \,.\, D - \bar{d}I \rangle}{\left\|D - \bar{d}I\right\|^2}$$

And (3)

$$o = \bar{r} - s\bar{d}$$

where $\bar{r}$ and $\bar{d}$ represent the mean intensity of the block R and D respectively and the symbol $\langle\, . \,\rangle$ denotes the inner product operation. In order to ensure the convergence in the iterated decoding process, the contrast parameter s should satisfy $|s|<1$ [4]. Once s and o are obtained, the error $E(R, D_i)$ can be computed. By $o = \bar{r} - s\bar{d}$ the error $E(R, D_i)$ can be further simplified as follows:

$$E(R, D_i) = \|R - (sD_i + oI)\|^2$$

$$= \|R - rI\|^2 - s^2\left\|D - \bar{d}I\right\|^2 = u - s^2 v \quad (4)$$

The domain block which results in the smallest error from (2) is selected as the best matched block and all the related parameters are stored. In the decoding process, the stored parameters are recursively applied to the initial image. Then the original image will be reconstructed after a few iterations.

In full search method, we need to compute many errors to encode the input image and it is very time-consuming. To reduce the computation complexity many methods were proposed. Out of which, Kick-out based techniques greatly reduce the required computation with similar decoded image quality.

III. Kick-out Based Techniques

Two Kick-out condition based techniques have been proposed. Out of which first method was proposed in 2003 by Lai et al's [16] based on single kick-out condition & the zero contrast prediction. Another method was proposed in 2009 by Hsiu et al's [17] based on normalized one-norm & kick-out condition.

A. *The kick-out & Zero contrast condition based method:-*

This method was proposed by Lai et al's[16]. The principle of proposed algorithm is to avoid those domain blocks which satisfy kick-out condition, so the longer computations time will be reduced. In this method, we first convert the full search (2) from two parameters (contrast and offset), to a function which only contains the contrast. Based on this formulation, we can consecutively eliminate the search space in the domain pool and thus decrease the computation required to compare a range block and a domain block.

By equation (4), we can write $E(R, D_i) = u - s^2 v$. Due to $|s|<1$, produces $E(R, D_i) \geq u - v$.

Let $E_x(R, D_i) = u - v$. Thus we may have,

$E(R, D_i) \geq E_x(R, D_i)$ (5)

For the input range block R, assume that D_{min} is the minimum error. For any domain block D, if the kick-out condition is,

$E_x\ (R, D_i) \geq D_{min}$ (6)

then we can write, $E(R, D_i) \geq D_{min}$.

This means that, the domain block D will not be the best matched block to the range block R and it can be Kicked out immediately.

In detail, a method was proposed to reject dissimilar domain blocks efficiently for a given range block. The matching errors of the first domain block with each of the eight isometry operations are calculated. The one with the minimum error is considered to be the initial best matched domain block. The current minimum distance is then set to this minimum distortion, and the search proceeds further. Similarly the actual distortion is calculated for the domain block with the eight isometry operations. If all the matching errors between the transformed domain blocks are larger than the current minimum error, than these domain blocks will be rejected. This process is repeated for all the domain blocks in the domain pool to find the best matched one for an input range block. Based on this kick-out condition, the required computation for searching the best matched domain block will be greatly reduced.

Inspite of, with equation (6), the zero contrast condition is also used to speed up the computation of the best matched domain block. From $E(R, D_i) = u - s^2 v \geq 0$ we can write,

$|s| \leq \sqrt{u/v}$ (7)

If the contrast parameter $|s| \leq 0.03125$, s will be quantized to 0. On the other hand, when $\sqrt{u/v} > 0.03125$, s is set to 0. Thus, the corresponding error is given by $E(R, D_i) = u$

This method also has a good computation speed and has the same decoded image quality as in the full search method.

This method can combine with other fast fractal algorithms to further improve their speed. In encoding an image, the single kick-out condition check to reject dissimilar domain blocks. Zero contrast condition is then used to determine whether the contrast factor is zero or not, and the corresponding error function can be computed without performing the range domain block matching. Therefore, the required runtime for the algorithm can be further reduced.

B. *Normalized one-norm & kick-out condition based method:-*

Another fractal image encoding method based on kick-out condition was proposed by Hsiu et al's [17] using normalized one- norm and kick-out condition. In this method, an inequality is derived & it can be used to remove the mismatched domain blocks at earlier stage in the process of finding the best matched domain block. In this method reconstructed image quality is equivalent as with the full search method.

Let consider an image block X, then its normalized block can be represent as $\hat{X} = (X - \bar{X}I)/\|X - \bar{X}I\|$. The one norm of the normalized range block $\hat{R}$ can defined as,

$$\left\|\hat{R}\right\|_1 = \sum_{i=1}^{n}\sum_{j=1}^{n}|\hat{r}_{ij}|$$

$$= \sum_{i=1}^{N}|\hat{r}_i| \quad (8)$$

where $\hat{r}_i$ denotes the ith element of $\hat{R}$. The normalized one-norm of the domain block D is denoted by $\left\|\widehat{D}\right\|_1$.

According to this method,

If $\left\|\hat{R}\right\|_1 \geq \left\|\widehat{D}\right\|_1$, it yields

$$E(R, D) \geq \frac{\|R - \bar{r}I\|^2}{N}\left\|\left\|\hat{R}\right\|_1 - \left\|\widehat{D}\right\|_1\right\|^2 \quad (9)$$

where $\frac{\|R - \bar{r}I\|^2}{N}$ is the variance of R.

From equation (9),

Let $E(R, D) = \frac{\|R - \bar{r}I\|^2}{N}\left\|\left\|\hat{R}\right\|_1 - \left\|\widehat{D}\right\|_1\right\|^2$ and D_{min} is assumed as the current minimum error,

than for $\left\|\hat{R}\right\|_1 \geq \left\|\widehat{D}\right\|_1$, the inequality is,

$E(R, D) \geq D_{min}$ (10)

If the matching error is larger than the current minimum error, than the domain block D will not be best matched block for range block R & it will be rejected immediately. By this method the reconstructed image quality is similar to that in full search method. This method presents a new inequality which can be used to eliminate the impossible domain blocks for the current range block efficiently.

IV. Comparison

A 512×512 Lena image is used to compare the performance of kick-out based methods with full search method in terms of execution time & decoded image quality. The decoded image quality is measured by PSNR (peak signal-to-noise ratio). In table, 'difference (%)' column shows improvement ratio with respect to full search method.

TABLE I.
EXECUTION TIME PERFORMANCE COMPARISON FOR 4×4 RANGE BLOCK

Methods			Difference (%)
Full Search	Time	255	0%
	PSNR	37.56	0%
Single kick-out condition & zero contrast prediction	Time	199	22%
	PSNR	37.56	0%
Normalized one norm & kick-out condition	Time	195	24%
	PSNR	37.56	0%

Table 1 demonstrate the comparison in execution-time & image quality in terms of PSNR for three concerned encoding methods. The execution-time will reduce by 22% for Lai's method & by 24% for Hsiu's method in comparison with full search method while the decoded image quality is similar to that full search method.

V. Conclusion

Kick-out condition based speed-up techniques provides remarkable improvement in time consumption. The single kick-out condition can avoid a large number of range-domain block matches when finding the best matched domain block. These methods can achieve the same decoded image quality as the full search, while reducing the computation time. The combination of other fast fractal encoding techniques with kick-out condition based techniques further improves the speed. In future, we can combine some other fast fractal algorithms with kick-out based methods to obtain inequalities which discard the unmatched domain blocks at the earlier stage of computation & reduce the execution time with same decoded image quality.

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