Discrete Wavelet Transform based Fractal Image Compression using Parallel Approach

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ABSTRACT
Fractal based technique for compression is one of the popular methods for compression of videos and images. It has generated much interest due to its promise of high compression ratios at good decompression quality and it enjoys the advantage of very fast decompression and resolution independent decoding .But it suffers from highly computationally intensive encoding process which makes it unsuitable for real time applications. Many approaches have been suggested but they do not satisfy the requirement of low encoding time and high quality reconstructed images. In this paper parallel algorithm for fractal image compression using NVIDIA`s GPGPU is proposed. Also novel discrete wavelet transform based feature detection is used to reduce the number of block comparisons. Experimental results show significant reduction in encoding time and quality of reconstructed images is also good compared to other approaches making this technique suitable for real time applications such as image retrieval, image denoising, Image authentication and encryption, satellite and medical imaging..

General Terms
Parallel computing, Image compression

Keywords
IFS, GPU, Fractals, Image Compression.

1. INTRODUCTION
A Fractal is defined as a mathematical set that typically exhibits self similar patterns, which means they possesses same structure at every scale .The idea of image compression using fractal theory was first proposed by Barnsley[1],he suggested that by exploiting the self similarity of image parts by means of certain metric and storing images as transforms could lead to image compression .First realization of fractal image compression scheme was introduced by jacquin[3]. The fractal image compression is based on exploiting the redundancies inside the image by means of block self-affine transformations.

Fractal Image Compression (FIC) has generated much interest due to its promise of high compression ratios and it enjoys the advantage of very fast decompression and resolution independent high fidelity images. Fractal image compression is applicable in wide verity of applications such as satellite imaging, medical imaging, image authentication and encryption, image de-noising, image retrieval etc.

To speed up the encoding process different approaches based on feature extraction, block classification and hybrid approaches combining transform coding and fractal method are proposed.[18][19][20]

Meanwhile, the increasing demands for high computational power led to the invention of general purpose computing on GPU (Graphics Processing Unit). Earlier the GPUs were designed and used only for graphics purpose. But, their high computational power attracted many researchers and eventually GPUs were used for general applications (which require high computations) with the help of graphics languages. NVIDIAs CUDA enabled GPU is one of the popular plat forms for implementing parallel algorithms. This motivates us to make use of GPGPU to reduce the encoding time of fractal image compression by developing parallel algorithm.

The objective of this work is, to design an efficient parallel algorithm to reduce the encoding time of conventional fractal encoding algorithm. By incorporating an efficient feature extraction technique such as discrete wavelet transform to reduce the number of range domain comparisons. NVIDIA'S GPGPU is used for parallel implementation of proposed algorithm. And also to exploit realistic use of fractal image compression technique in the areas such as image retrieval, image de-noising, Image authentication and encryption, satellite and medical imaging.

The remaining sections are organized as follows. In Section II we discuss some approaches to fractal image compression, section III describes baseline FIC, section IV contains proposed method, and section V shows experimental results.

2. LITERATURE SURVEY FOR FIC
An efficient classification technique based on average and mean of pixel intensities was proposed by Boss, Fisher, and Jacobs [4]. Hassaballah et al [5] used Entropy based approach to classify the domain blocks. Fidelity of reconstructed image is poor in this case. Wang Hai et al [6] proposed Graph-based image segmentation approach to separate an input image into many different logic areas according to image content and to construct search space for each logic area. Each logic area is encoded using adaptive threshold quad-tree approach for fast image compression. Kung et al used one dimensional DCT [7] for feature extraction and blocks are classified into 4 types of edges. The structure similarity (SSIM) index is used instead of MSE to reduce computation complexity. Chen et al [8] proposed Kick-out method to discard impossible domain blocks based on one –norm in early stage of current range block is used, in this method for the comparison of range and domain blocks normalization of range and domain block is performed. In parallel approach by Palazzari et al [9] the image is divided into blocks each block is processed by the one processor. Each processor executes sequential algorithm on its block and returns the result. Limitation of this approach is it uses coarse grained input data. i.e. each processor only works on the subset of domain blocks this result in insufficient mapping. So the resultant image will be inferior to sequential approach. Furao & Hasegawa [10] has proposed fractal coding method based on without search.

Wavelets transform and Diamond search based hybrid fractal coding proposed by Zhang et al[11]. In this method diamond search is applied to find matching domain block with range block, like motion estimation technique in video compression.

GPU based fractal image compression for medical imaging is demonstrated [12].results shows drastic reduction in encoding time due to use of parallel approach.Cluster of GPU is used for fractal image compression by Chauhan et al [13]. In this approach domain pool is divided on to slave machines by master node and range blocks are circulated in pipelined manner across all slaves till the match is found .if match is not found then master divides the range and re-circulate it.

Wang et al[14]used absolute value of Pearson correlation coefficient to classify domain blocks. Range blocks are restricted to search in area of sorted list where correlation is maximum.

3. FRACTAL IMAGE COMPRESSION SYSTEM

Block diagram shown in fig 1 indicates the fractal image compression system. Image can be acquired by using digital camera, satellite, medical image device, Image retrieval system etc. Output of the system can be used for transmission, in image retrieval system, image authentication system etc.

The block based fractal image compression was first realized by Jacobs et al [4], this implementation was based on partitioned Iterated function System (PIFS). Baseline algorithm for partitioned Iterated function System based fractal encoding is as follows.

Step 1. Read input image.

Step 2.Partition image into non overlapping range blocks of size n*n.

Step 3.Partition image into overlapping domain blocks of size 2n*2n.

Step 4.For every range block find domain block which minimizes equation 1.

Step 5.Store transformation parameters to encode file.

Given two image blocks of n pixel intensities $d1, d2, \ldots . dn$ from Di(domain) and $r1, r2, \ldots . . rn$ from Ri(range) Using RMS metric optimal values for $s_k$contrast setting and $o_k$brightness setting are computed to minimize equation 1.

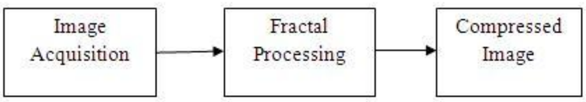

Fig 1. Fractal Image Compression System

$$E = min(\|r_i - (s_k d_k + o_k)\|)\ k = 1,2 \ldots .7 \tag{1}$$

Where $s_k$and $o_k$are calculated as.

$$s_k = \frac{\langle n \sum_{i=0}^{n} d_i r_i - \sum_{i=0}^{n} d_i \sum_{i=0}^{n} r_i \rangle}{\langle n \sum_{i=0}^{n} d_i^2 - \left(\sum_{i=0}^{n} a_i\right)^2 \rangle} \tag{2}$$

$$o_k = \frac{1}{n}\left[\sum_{i=0}^{n} r_i - s_k \sum_{i=0}^{n} d_i\right] \tag{3}$$

Before comparing domain blocks are down sampled by taking average of four neighbouring pixels so as to make domain blocks equal to size of range blocks. After this each domain block is compared with range block by applying eight different affine transformations [3].

This fractal coding algorithm based on PIFS provides a suboptimal solution. For encoding the image using PIFS, the most similar domain block in large domain pool of each range block has to be found. For each domain block contrast scaling and brightness shift are calculated by using equation (2) & (3) the domain block which minimizes equation (1) will be considered as best matching domain block. The fractal affine transformation for domain block is expressed as.

$$W\begin{bmatrix} x \\ y \\ d_k \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & 0 \\ a_{21} & a_{22} & 0 \\ 0 & 0 & s_k \end{bmatrix} \begin{bmatrix} x \\ y \\ d_k \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \\ o_k \end{bmatrix} \tag{4}$$

For given range block $r_i$along with affine transform (4) the values for s_k,o_k,k will be computed . In practice, tx, ty, s_k,o_k, and k can be encoded using 8, 8, 5, 7 and 3 bits, respectively, which are regarded as the compression code of r_i.

4. PROPOSED FIC BASED ON DWT AND PARALLEL APPROACH

Baseline algorithm requires large number of MSE calculations which is computationally intensive task, increases the time required for encoding .In our approach to reduce the encoding time we are using block classification method .After classification we are applying parallel approach for comparing the range blocks with domain blocks in the same class.

4.1 Haar Wavelet Transform

Before describing the working of classification algorithm, we briefly go through Haar wavelet transformation. Which we are using as classifier. Wavelets are used as basis functions $\psi k(t)$ in representing other functions $f(t)$i.e.. $f(t) = \sum_k a_k \psi_k(t)$ Wavelet transform gives us both spatial and frequency correlation of data by applying scaling and translation of mother wavelet on input data. The major advantage of wavelet transform is it provides multi resolution analysis i.e.it can be applied to different scales according to the details required. Prototype function for mother wavelet will be as follows.

$$\psi = {}^{1}\!/_{\sqrt{a}}\, \psi\left(\frac{t-b}{a}\right) \tag{5}$$

Where a is scaling parameter,b is translation parameter, t is time. Once the mother wavelet is fixed one can form basis from it by applying translation and scaling.

Mother scaling function for Haar wavelet is defined as

$$\varphi(x) = \begin{cases} 1 & if\ 0 \le x \le 1 \\ 0 & otherwise \end{cases} \tag{6}$$

The basis function for Haar wavelet is defined as

$$\varphi_i^j = \varphi(2^j x - i)\ \ i = 0,1,2, \ldots \ldots 2^j - 1 \tag{7}$$

Similarly mother wavelet function for Haar wavelet is defined as.

$$\psi(x) = \begin{cases} 1 & if\ 0 \le x \le 1/2 \\ -1 & if\ 1/2 \le x \le 1 \\ 0 & otherwise \end{cases} \tag{8}$$

The basis function for mother wavelet is defined as.

$$\psi_i^j = \psi(2^j x - i)\ \ i = 0,1,2, \ldots \ldots 2^j - 1 \tag{9}$$

The above functions provide us one dimensional Haar wavelet transform. Image is two dimensional signal in spatial domain. We can obtain two dimensional Haar wavelet function which is a generalisation of one dimensional Haar wavelet. Two dimensional scaling functions are obtained by multiplying two one dimensional scaling functions such as$(x, y) = \varphi(x)\varphi(y)$. Wavelet function can be obtained by multiplying two wavelet or one scaling and one wavelet function. $\Psi(1)(x, y) = \varphi(x)\Psi(y)$Captures the details in horizontal direction, $\Psi(2)(x, y) = \Psi(x)\varphi(y)$ captures the details in vertical direction, $\Psi(3)(x, y) = \Psi(x)\Psi(y)$ in diagonal direction. Thus if we apply Haar DWT to image it get decompose into 4 bands such as (LL) average,(LH) vertical details, (HL) horizontal details, (HH) diagonal details.

4.2 DWT for classification

The underlying idea of a classifier is that blocks tend to be similar to blocks of the same type. The classification algorithm mainly aims at categorizing the whole image blocks (range and domain) into four class's .From the spatial domain image block can be transformed into frequency domain by means of Discrete Wavelet Transformation. Block size is considered as 8*8 pixels. For each extracted image block (i.e. range / domain) DWT is applied as described in the previous section. Apply DWT over a quadrant which contains average coefficients, till a block resolution becomes 2*2. At this resolution we get four coefficients representing average (upper left), horizontal difference (upper right), Vertical difference (lower left), diagonal difference (lower right). To classify the image block, these three differences are used. Out of these three differences whichever is greater, pixel intensities variation is more in that direction. If the horizontal difference is greater than other two differences for a particular block then that block is having major intensity variation in horizontal direction so that block is classified as horizontal block .Similarly vertical and diagonal blocks can be classified. Now the maximum among these three differences is compared with some threshold value if maximum is less than the threshold (Th), block is considered to be smooth. That indicates there is no significant variation of pixel intensities in any direction.

For parallel comparison of range block and domain block NVIDIA's CUDA enabled GPU is used. Before comparison starts entire domain pool and range pool is transferred to global memory of GPU device. The number of thread blocks launched is equal to number of range blocks in a class. Each thread block is assigned a task of comparing range block to all domain blocks. All the thread blocks launched simultaneously so each range block gets compared in parallel with all domain blocks. This scheme of parallel range and domain comparison significantly reduces the encoding time. Block diagram in fig.2 shows the execution of proposed method. Algorithm 1 gives the procedure for image compressing.

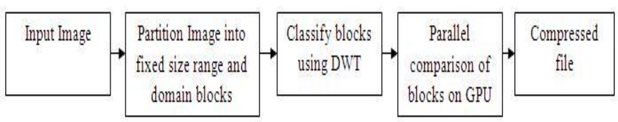

Fig 2. Block diagram for proposed method

Algorithm1. **Modified FIC Algorithm**

Step 1*: Read the image of size MxN into a matrix.*

Step 2*: Partition the image into non-overlapping square blocks of size nxn, and form the set R of range blocks.*

Apply DWT to each range block as

Step 3*: Partition the image into overlapping square blocks of size 2nx2n, and form the set D of domain blocks.*

Apply DWT to each domain block as

Step 4*: Copy entire domain and range blocks to GPU*

Step 5*: Carry out comparison of all range blocks in parallel with all domain blocks*

Step 6*: Copy fractal code for every range block to host memory.*

Step 7*: Write fractal code for every range block to encode file.*

PSNR, SSIM and encoding time are used as evaluation parameters.

PSNR is peak signal to noise ratio which is used to evaluate the quality of reconstructed image. It is defined as follows.

$$PSNR = 10 * log_{10}\left(\frac{MAX^2}{MSE}\right) \quad (10)$$

Where MSE is

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \quad (11)$$

The structural similarity (SSIM) index is a method for measuring the similarity between two images. SSIM is used to overcome the drawbacks of traditional methods like peak signal-to-noise ratio (PSNR). The difference between SSIM and PSNR is that PSNR estimate perceived errors; SSIM considers change in structural information. Structural information is the idea that the pixels have strong inter-dependencies with neighboring pixels. These dependencies carry important information about the structure of the objects in the visual scene. The value of SSIM is between [0,1],SSIM=0 indicates dissimilar images and SSIM=1 indicates exactly similar images. It is defined as follows.

$$SSIM = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (12)$$

Where μ_x average of x, μ_y average of y, σ_x^2 variance of x, σ_y^2 variance of y, σ_{xy} co variance of x and y.

5. EXPERIMENTAL RESULTS

The proposed DWT & Parallel block classification comparison method is simulated and verified .Sequential execution of proposed algorithm is carried out on Intel Pentium IV 3.06G,1GB of RAM ,on Windows XP platform, using C++.Parallel implementation of proposed method is carried out on NVIDIA GeForce GTX 480 Graphics Processing Unit. Using CUDA C programming language. Experimental results are carried out on 6 standard test images. Barbara, Elaine, Boat, Couple, Bridge, Arial-plane all of size (512x512x8). Fig.6 shows original image Barbara and decompressed image after 5 iterations.

Figure 3 is the plot for comparison of encoding time required for full search algorithm and proposed algorithm on CPU and GPU. Proposed classification scheme is evaluated on CPU without parallel comparison and on GPU parallel approach is used. Comparison results show that the visual effect is better and the average speed up ratio of proposed method over full search method is 298.32. Figure 4 is the plot for comparison of PSNR for full search algorithm and proposed algorithm. Figure 5 is the plot for comparison of SSIM for full search algorithm and proposed algorithm. Results in this graph indicate the structural similarity of decoded image is very much close to the original image.

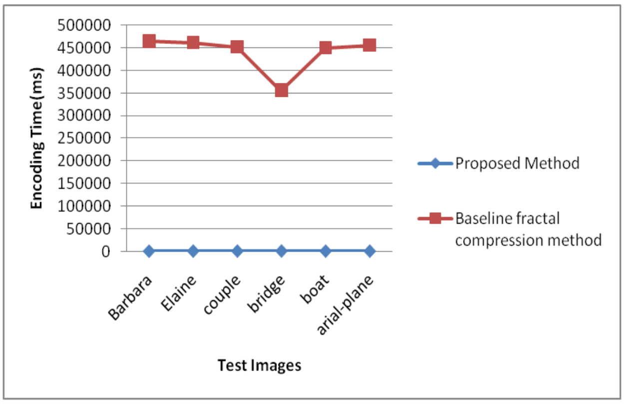

Fig 3 Encoding Time(ms) .

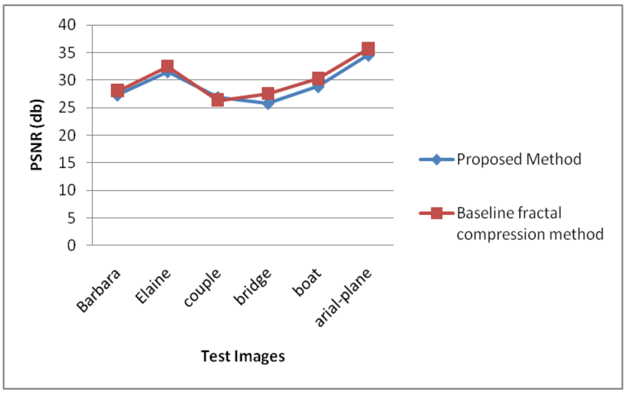

Fig 4 Comparison of PSNR(db)

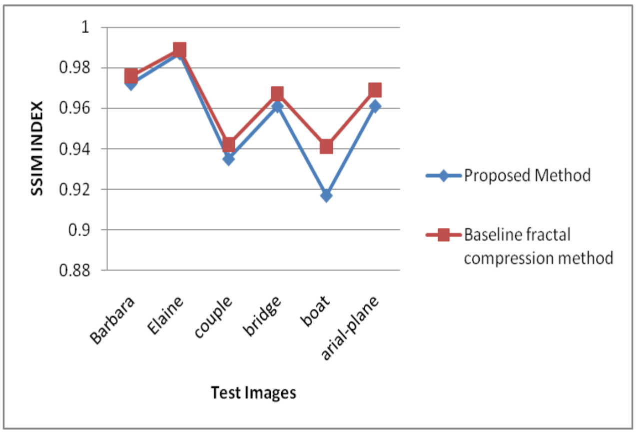

Fig 5 Comparison of SSIM

6. CONCLUSION

In this paper, DWT and Parallel block classification and comparison method is equipped into the fractal image compression to speed up the encoder. Experimental results show that the visual effect is better and the average speed up ratio of proposed method over full search method is 298.32. This indicates significant reduction in encoding time of conventional full search fractal image compression method. Proposed method can be extended for the compression of video by using suitable motion compensation and motion estimation technique.

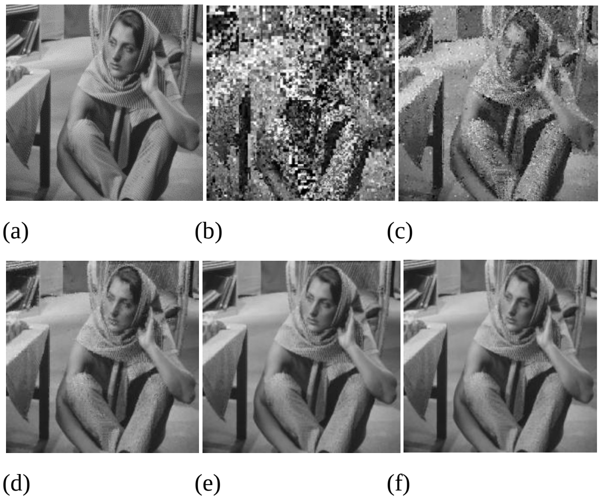

Fig 6 a) Original Barbara image b) decoded image after 1st iteration c) decoded image after 2nd iteration d) decoded image after 3rd iteration e) decoded image after 4th iteration (f) decoded image after 5th iteration.

7. ACKNOWLEDGMENT

My deepest gratitude goes first and foremost to Professor Mr.B.A.Sonkamble, my M.E. Guide, for his constant encouragement and guidance. he has walked me through all the stages of the writing of this article. Without his consistent and illuminating instruction, this article could not have reached its present form. At the same time, I also owe my sincere gratitude to my colleagues who gave me their help and time in listening to me and helping me work out my problems during the difficult course of the article. Last my thanks would go to my beloved family for their loving considerations and great confidence in me.

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