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Digital Image Compression Using Genetic Algorithms

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Abstract

The idea of image compression is to process an image in such a way that its output representation requires to be transmitted or stored in a reduced size. In this paper, we solve the image compression problem using genetic algorithms (GAs) based on the pixels of the image. The technique described here utilizes the GA, which greatly decreases the search space for finding the Peak Signal-to-Noise Ratio (PSNR) and Compression Ratio (CR). PSNR and CR are used to construct the fitness function for set of chromosomes in this work. During the compression, the advanced wavelet coding schemes (soft or hard threshold compression) are used. Several experiments were given to illustrates the performance of the proposed scheme and it give good results to image compression.

Keywords: Genetic algorithms, Image compression, Wavelet transform.

1. Introduction

The use of image communication has increased in recent years. Uncompressed graphics, audio, and video data require considerable storage capacity and transmission bandwidth. Despite rapid progress in mass-storage density, processor speeds, and digital communication system performance, demand for data storage capacity and data transmission bandwidth continues to outstrip the capabilities of available technologies.

The idea of image compression is to process an image in such a way that its output representation requires to be transmitted or stored in a reduced size, either with no loss in quality (lossless compression) or with some (tolerable) reduction in image quality. Image compression techniques can be operated on one or a number of aspects of image representation; e.g. we may try to reduce the number of pixels in an image, which will consequently minimize the number of bits required to represent that image [2, 9]. Image data compression is essential for communication applications such as TV transmission, video conferencing, graphics, or transmission for remote sensing of image obtained from satellites and reconnaissance aircraft and ECG (Electro-Cardio-Gram) signal compression, as well as, multimedia applications.

Wavelet Transform is one of the most powerful tools in digital signal processing. The image components are decomposed into different decomposition levels using a wavelet transform. These decomposition levels contain a number of subbands, which consist of coefficients that describe the horizontal and vertical spatial frequency characteristics of the original image component [1]. Power of 2 decompositions are allowed in the form of standard decomposition. To perform the forward Discrete Wavelet Transform (DWT), the standard uses a two dimension (2-D) subband decomposition of a 2-D set of samples into low-pass samples and high-pass samples. Low-pass samples represent a downsampled low-resolution version of the original set. High-pass samples represent a downsampled residual version of the original set, needed for the perfect reconstruction of the original set from the low-pass set. It is mainly used to de-correlate the image data, so the resulting wavelet coefficients can be efficiently coded. It also has good energy compaction capability that results in a high compression ratio [4].

GAs work on a coding of the parameters set over which the search has to perform, rather than the parameters themselves. These encoded parameters are called ***solutions*** or ***chromosomes*** and the objective function value at a solution is the objective function value at the corresponding parameters [3, 7]. GAs solve optimization problems using a population of a fixed number solutions. A solution is a string of symbols. GAs evolve over ***generations.*** During each generation, they produce a new population from the current population by applying genetic operators ***viz., natural selection, crossover, and mutation***. A solution consists of a string of symbols, typically binary symbols. Each solution in the population is associated with a figure of merit (fitness value) depending on the value of the function to be optimized. The selection operator selects a solution from the current population for the next population with probability proportional to its fitness value [10, 13]. Crossover operates on two solution strings and results in another two strings. Typical crossover operator exchanges the segments of selected strings across a crossover point with a probability called ***crossover probability (Pc)***. The mutation operator toggles each position in a string with a probability, called ***mutation probability (Pm)*** [6].

In 1998, Mitra *et al.* [8] proposed a new method for fractal image compression using GA with elitist model. In 2007, Shanmugalakshmi and Annadurai [11], introduced a hybrid technique which combines the advantages of the assortative mating in genetic algorithms and genetic simulated annealing algorithm for codebook generations. In present study, the image compression problem using genetic algorithm has been suggested.

2. Basic Principles

2.1 Genetic Algorithms

To apply a genetic algorithm to any practical problem, it requires seven steps as shown as shown in Figure (1) [3, 5].

Step 0: <u>Parameter Assignment.</u>

Give the value of control parameters, such as population size (Popsize), Pc and Pm ∈ [0, 1], threshold of fitness function (ThrFit), maximum number of generations (Maxgen).

Step 1: <u>Initialization.</u>

Generate the initial population at random.

Step 2: <u>Evaluation</u>.

Evaluate each individual in the population.

Step 3: <u>Selection.</u>

Select individuals from population to mate.

Step 4: <u>Mating.</u>

Apply genetic operators (crossover, mutation).

Step 5: <u>Replacement.</u>

Apply replacement policy, the new child replaces with worst chromosomes.

Step 6: <u>Termination.</u>

If halt criterion has been reached, then stop else go to step 2.

Figure (1): GA cycle.

2.2 Wavelet Transform

The wavelet transform performs an octave subband decomposition of an image. The output of the first analysis stage is the low-low (LL) subband (an approximation of the original image); the high-low (HL) subband (the horizontal detail); the low-high (LH) subband (the vertical details); and, the high-high (HH) subband (the diagonal details).

Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information [9]. The low-frequency content is the most important part. It is what gives the signal its identity. The high-frequency content, on the other hand, imparts flavour or nuance. Subband coding is a coding strategy that tries to isolate different characteristics of a signal in a way that collects the signal energy into few components. This is referred to as energy compaction [12].

2.3 Thresholding

Threshold quantization performs a quantization process of an image by using wavelet transform. It restores a compressed version of input image

obtained by wavelet transform. Coefficients thresholding using global positive threshold value (THR) is applied. Wavelet decomposition is performed for n levels [2].
There are two types of thresholding process. The first type is *soft thresholding*, which is calculated using equation (1):

$$Y = \begin{cases} Sign(X)(|X| - THR), & if \quad |X| > THR \\ 0 \quad , & if \quad |X| \le THR \end{cases} \quad \ldots(1)$$

Sign: sign of X

The second type is *hard thresholding*, which is calculated using equation (2):

$$Y = \begin{cases} X, & if \quad |X| > THR \\ 0, & if \quad |X| \le THR \end{cases} \quad \ldots(2)$$

Where, X: is the input vector or matrix.
THR: is the threshold value.

The quantization procedure contains three steps [2]:

1. Decomposition.
2. Detail coefficient thresholding. For each level from 1 to n, a threshold is selected and soft or hard thresholding is applied to the detail coefficients.
3. Reconstruction.

3. Proposed Algorithm

Image compression problem using genetic algorithms is based on the pixels of the image. The aim of GA presented here is to find the compression parameters, i. e., the threshold value, type of threshold, keep approximation or not, number of wavelet analysis levels, and wavelet filter name. In threshold compression method, the chosen results are used to find image compression. This section concentrates on the description of the GA steps to the problem of searching through the parameters of compression method.

3.1 Chromosome Representation

The initial population of the chromosomes is generated at random. These chromosomes represent the compression parameters. The chromosomes in the population have a fixed length. Each chromosome is contains five genes (G_1, G_2, G_3, G_4, and G_5): the first gene (G_1) represents the threshold value, the second gene (G_2) represents type of threshold, the third gene (G_3) represents keep approximation or not, the fourth gene (G_4) represents No. of wavelet analysis levels, and the fifth gene (G_5) represents wavelet filter name. Figure (2) shows the representation of the chromosome.

0..255	1 or 0	1 or 0	1..8	1..10
G_1	G_2	G_3	G_4	G_5

Figure (2): Chromosome structure in a population.

Used wavelet filter name: 1: bior6.8, 2: db3, 3: db5, 4: db1, 5: coif2, 6: sym4, 7: sym2, 8: db8, 9: bior1.3, 10: coif2.

3.2 Fitness Function

The next step is to create a fitness function that will evaluate how well each chromosome solves the problem; that is, calculates the fitness of the chromosomes. The evaluation function used in this work is based on both the PSNR and CR. The following fitness function is used in the current scheme:

$$Fitness = alpha * PSNR + beta * CR \quad \ldots (3)$$

where, *Fitness*: fitness function,

Alpha and *beta*: real constants between 0 and 1, that alpha + beta = 1.

PSNR is the standard method for quantitatively comparing a compressed image with the original. For an 8-bit grayscale image, the peak signal value is 255. Hence, the PSNR of an M×N 8-bit grayscale image x and its reconstruction $\hat{x}$ is calculated as:

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \quad \ldots (4)$$

where the Mean Square Error (MSE) is defined as [4]:

$$MSE = \frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}[x(m,n) - \hat{x}(m,n)]^2 \quad \ldots (5)$$

PSNR is measured in decibels (dB), M: height of the image, N: width of the image.

The No. of zeros pixels of the image to the No. of total pixels of the same image multiply by 100 is the compression ratio (*CR*). It is defined as [4]:

$$CR = \frac{No.\ of\ zeros\ pixels}{No.\ of\ total\ pixels} * 100\ \% \quad \ldots (6)$$

If alpha > beta then has to obtain a high-quality decoded (reconstructed) image (high PSNR). While alpha < beta, has to obtain a high compression ratio (high CR). If alpha = beta, thus a trade-off has to obtain a good quality decoded image with a considerable amount of compression.

3.3 Selection Strategy

The selection of the parents to create the next generation is based on the fitness of the chromosomes. The probability of selection of any chromosome is proportional to its fitness; thus, fitter chromosomes are more likely to be selected for reproduction.

For the purpose of this study, we have used *Roulette Wheel Selection* which assigns a probability to each chromosome ,i , and it is computed as the proportion [10]:

$$F(i) = \frac{f_i}{\sum_{j=1}^{n} f_j} \qquad \dots (7)$$

3.4 The Mating Process

The crossover operator is repeatedly applied to pairs of chromosomes. The process of the two crossing chromosomes involves randomly the selection of different locuses for each chromosome, and then swapping between the two chromosomes their genetic materials. During this work, uniform crossover operator is used. In the uniform crossover operator [11], each gene is selected randomly, either from the first parent or from the second one, based on the mask (template). For e.g.,

Parent 1 : A B C D E F   Child 1 : G B C J E L
Parent 2 : G H I J K L   Child 2 : A H I D K F
Mask   : 0 1 1 0 1 0

For each chromosome, with certain probability, a mutation site is selected and altered. Any one of the parameters is altered to a new random value, based on the probability of mutation. A genetic mutation for a random site, changes its old gene value to a random new value. Mutation operator which was used in this study involves one-point mutation (1m).

3.5 Replacement Policy

During our study, we used the Holland technique which the offsprings are replaced with poor chromosomes in population [3]. The child replaces the parent after applying crossover and mutation.

3.6 Termination Condition

Termination condition is made either threshold of fitness function greater than an input threshold value or the maximum number of generations is reached. GA continues repeating until one of the above conditions is achieved.

3.7 The Complete Genetic Algorithm

The above processes are combined to create the complete GA. The steps of the algorithm are as shown in Figure (3).

Algorithm Digital-Image-Compression

Input: Popsize [population size]
Maxgen [maximum number of generations]
Pc [crossover probability]
Pm [mutation probability]
ThrFit [threshold of fitness function]
Alpha [percentage of PSNR]
Beta [percentage of CR]

Output: Compression parameters [threshold value, type of threshold, keep approximation or not, No. of wavelet analysis levels, wavelet filter name]

Begin

1- A random population of candidate compression parameters is generated.

2-A fitness value for each candidate in compression parameters in the population is computed.

3- Find the chromosome of higher fitness value.

4- If its fitness = an input threshold value then, perform a fixed number of the GA generations to find the PSNR and CR, otherwise continue.

5- A biased (based on fitness) random selection of parents is conducted.

6- The uniform crossover operation is applied to the selected parents with Pc (0.85).

7- The mutation process is applied to the children with Pm (0.23).

8- Go to step 2 if the stop conditions not terminate.

End

Figure (3): The Complete Genetic Algorithm

4. Experimental Results

In this section, we present a number of experiments which are used to examine our proposed version of the genetic algorithm in solving the compression problem. To evaluate the algorithm with a given set of operators and parameters settings, we performed a series of ten independent runs.

The algorithm is programmed in MATLAB version 6.5 on a Pentium IV PC (3 GHz) using four grayscale images of size (256×256) pixels; each pixel is represented by 8 bit/pixel. In order to perform testing, the following parameters were used:

Population size: 10
Maxgen: 50
Pc: 0.85
Pm: 0.23
ThrFit: 100

Experiments

In these experiments, digital image compression scheme is considered. Three different constant values for alpha and beta are applied. The following proposed algorithm according to these constant values will be tested:

Experiment 1

We propose here to the processing of compression image by using alpha = beta = 0.5. Results obtained by applying this method are presented in Table (1). Figure (4) shows the results obtained for cameraman image.

In Table (1), the first column gives the grayscale test image. The second column gives the threshold value. The third column gives the type of threshold. The fourth column gives the keep approximation or not. The fifth column gives the No. of analysis levels. The sixth column gives the wavelet filter name. The seventh column gives the PSNR of the reconstructed image. Finally, The eighth column gives the CR.

Table (1): Results of experiment 1.

Grayscale Image	Threshold value	Type of threshold	Keep approximation or not	No. of levels	Wavelet name	PSNR (dB)	CR (%)
Cameraman	62	hard	not keep	6	coif2	27.1734	96.3549
Peppers	60	hard	keep	6	db1	27.1479	95.8054
Boat	89	hard	keep	6	db1	23.3430	97.8806
Map	88	hard	keep	6	sym4	24.5170	98.3319

(a) (b)

Figure (4): Results of experiment 1 using alpha = beta = 0.5.
(a) Original grayscale cameraman image
(b) Reconstructed image at PSNR = 27.1734 dB, CR = 96.3549 %

Experiment 2

We propose here to the processing of compression image by using alpha > beta (i. e., alpha = 0.7, beta = 0.3). Results obtained by applying this method are presented in Table (2). Figure (5) shows the results obtained for cameraman image.

Table (2): Results of experiment 2.

Grayscale Image	Threshold value	Type of threshold	Keep approximation or not	No. of levels	Wavelet name	PSNR (dB)	CR (%)
Cameraman	28	hard	not keep	4	db5	31.4060	91.1971
Peppers	22	hard	not keep	5	coif2	33.6730	87.4860
Boat	30	hard	keep	5	coif2	29.3689	89.6319
Map	43	hard	keep	4	coif2	27.3015	94.6704

(a) (b)

Figure (5): Results of experiment 2 using alpha = 0.7, beta = 0.3.
(a) Original grayscale cameraman image
(b) Reconstructed image at PSNR = 31.4060 dB, CR = 91.1971 %

Experiment 3

We propose here to the processing of compression image by using alpha < beta (i. e., alpha = 0.3, beta = 0.7). Results obtained by applying this method are presented in Table (3). Figure (6) shows the results obtained for cameraman image.

Table (3): Results of experiment 3.

Grayscale Image	Threshold value	Type of threshold	Keep approximation or not	No. of levels	Wavelet name	PSNR (dB)	CR (%)
Cameraman	116	hard	not keep	6	coif2	24.0393	98.3046
Peppers	126	hard	not keep	5	coif2	24.4433	97.0917
Boat	129	hard	keep	7	db1	21.9174	98.9105
Map	118	hard	keep	5	coif2	23.6656	98.6933

(a) (b)

Figure (6): Results of experiment 3 using alpha = 0.3, beta = 0.7.
(a) Original grayscale cameraman image
(b) Reconstructed image at PSNR = 24.0393 dB, CR = 98.3046 %

5. Conclusions

Image digital compression technique described here utilities the GA, which greatly decreases the search space for finding the compression parameters. These parameters lead to compute PSNR and CR as the fitness function for set of chromosomes in this work. This is fully described in Tables (1, 2, and 3).

Based on the results obtained and detailed in the previous sections, we conclude the following:

- The GAs constitute a powerful tool that can succeed in constructing a compression method.
- Optimization of control parameters for GA has been made. From these results:
  - o If we need high-quality reconstructed image (high PSNR), the alpha must be greater than 0.5, as shown in Figure (5).
  - o If we need high compression ratio (high CR), the beta must be greater than 0.5, as shown in Figure (6).
  - o Thus, a trade-off has to be made to obtain a good quality reconstructed image with a considerable amount of compression (when alpha = beta = 0.5), as shown in Figure (4).
- The proposed system requires less computational time compared to the related heuristic search, in which GA is used to reduce the number of trails to solve image compression problem.
- Threshold compression is a good technique to digital image compression, so the CR is very high (CR > 87 %).
- During our experiments, we find that as the alpha value is increased, the PSNR is increased as well. Figure (7) shows PSNR versus the alpha value for cameraman image. On the other hand, we find that as the beta value is increased, the CR is increased as well. Figure (8) shows CR versus the beta value for cameraman image.

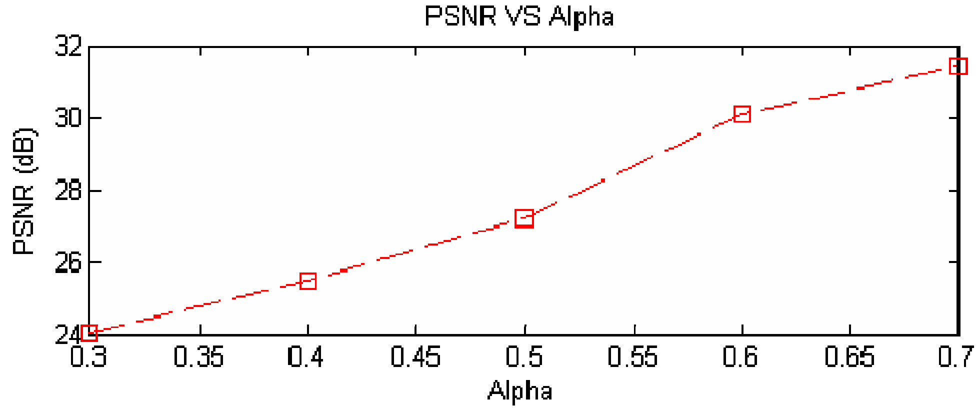

Figure (7): PSNR versus alpha for cameraman image

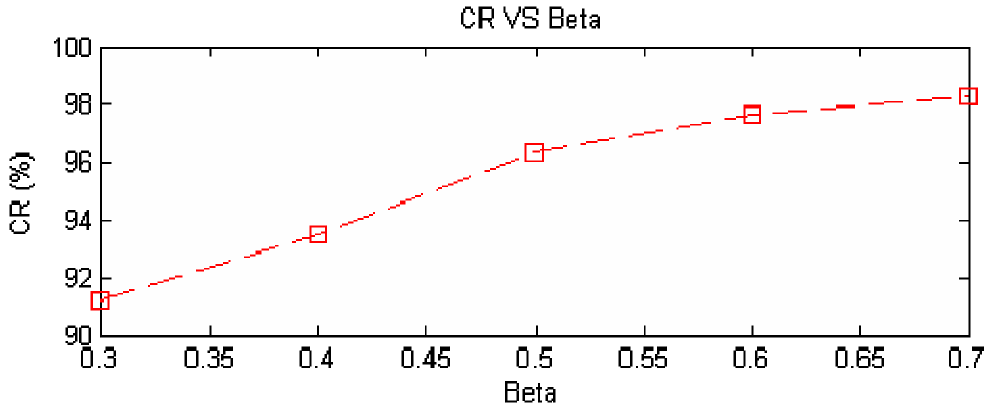

Figure (8): CR versus beta for cameraman image

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ضغط الصورة الرقمية باستعمال الخوارزميات الجينية

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المستخلص

الفكرة من ضغط الصورة هي معالجة الصورة بحيث إن تمثيل المخرجات يتطلب حجم صغير لغرض خزنها أو نقلها. في هذا البحث, تم حل مسألة ضغط الصورة باستعمال الخوارزميات الجينية اعتمادا على عناصر الصورة (pixels).
يمكن الاستفادة من الخوارزمية الجينية هنا لتقليل مجال البحث بصورة كبيرة لإيجاد نسبة قمة الإشارة–إلى–الضوضاء Peak Signal-to-Noise Ratio (PSNR) ونسبة الضغط Compression Ratio (CR) والتي استخدمت لإنشاء دالة تقييم لمجموعة الكروموسومات في البحث. خلال عملية الضغط, استخدمت تقنيات ترميز التحويل المويجي المتقدمة مثل (قيم عتبة ناعمة وخشنة). العديد من التجارب شرحت انجازية الطريقة المقترحة وأعطت نتائج جيدة لضغط الصورة.

الكلمات المفتاحية: الخوارزميات الجينية, ضغط الصورة, التحويل المويجي.