Mutual Multi-image Compression Based on Fractal Mating Coding

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Abstract

Conventional fractal coding techniques explore only the self-similarity in an image (i.e., the intra-image similarity) to achieve compression. In this paper, the fractal mating coding (FMC) method that also utilizes the similarity between two or more images (i.e., the inter-image similarity) is proposed. In the proposed FMC method, two or more images are mutually encoded and decoded. This provides the security/protection property that only the mutually encoded images can be correctly decoded. The computer experiments for the proposed FMC method are provided and the simulation result shows that the peak signal-to-noise ratio can be improved in average more than 1 dB under the same bit rate for the test images.

1 Introduction

Fractal-based image coding techniques have been received a great deal of attention since last decade [1]. The idea is originated from that the natural images have large self-similarity, which can be represented by the affine transformation [2]. Therefore, an image can be coded by the parameters (fractal code) denoting the contractive affine transformations. In 1992, Jacquin proposed the first fractal block coding technique that can automatically encode an image by the use of partitioned iterated function system [3]. Basically, an image is partitioned into the domain blocks and range blocks. For each range block, all of the domain blocks defined in the same image are searched for finding an affine-transformed domain block which is the most closest to the range block.

In currently image coding techniques, such as JPEG [4] and JPEG2000 [5] standards, an image is always independently encoded and decoded. Conventional fractal coding techniques search the self-similarity between the range and domain blocks in an image and thus the image is also encoded and decoded independently. However, the high self-similarity between the domain and the range blocks in an image does not always exist. To expand the variety of the domain pool, here we propose the fractal mating coding (FMC) method for images. In addition to the self-similarity in an image, the inter-similarity within two or more images is also explored. For the images with strong inter-similarities, the proposed FMC method can greatly improve the rate-distortion performance. If the dissimilar images are mutually coded, the rate-distortion performance is still well preserved. On the other hand, the proposed FMC method provides a secured transmission/storage for compressed images. For the users without the information that which two images are mutually coded, they cannot correctly retrieve the images. This is a promising feature in addition to the compression purpose.

2 Fractal Mating Coding (FMC) Method

The block diagram of the proposed FMC method for image coding framework is shown in Fig. 1. In the encoding stage shown in Fig. 1(a), n images \( f_1, f_2, \ldots, f_n \) are simultaneously considered in designing the domain pool. To construct the domain pool for certain specific image, for example the image \( f_1 \), the domain blocks can be selected from self and other images. Basically, the construction the domain pool for the image \( f_1 \) can be divided into two parts:

1. First, the domain blocks are selected from the image \( f_1 \) itself. Here the \( N_1 \) neighboring blocks located in a neighboring region of the current block are selected [9].
2. Second, the \( N_2, N_3, \ldots, N_n \) domain blocks are selected by uniformly subsampling other images...
3 Experimental Results

In the computer simulation, two numbers of images $(n = 2$ and $n = 3$) are mutually coded based on the proposed FMC method. Firstly, two 512×512 images (Lena and Peppers) with the eight-bit grayscale resolution are used to test the proposed FMC method. The performance of the decoded image is evaluated by the PSNR and the bit rate. In our simulation, an image is partitioned into range blocks of a single size, either 8×8 or 4×4; or an image is partitioned into two-level block sizes: 8×8 and 4×4. A general form for the PSNR of the decoded image is defined as

$$
\text{PSNR} = 10 \log_{10} \frac{255^2 \cdot 512^2}{\sum_{i,j=1}^{512} [f(i,j) - \hat{f}(i,j)]^2}.
$$

where $f(i,j)$ and $\hat{f}(i,j)$ denote the $(i,j)^{th}$ pixel values in the original and the decoded images, respectively. For all the cases in our simulation, we set 25 to the threshold values $E_{\text{th}}$ for the variance of 8×8 and 4×4 range blocks. The number $N$ of domain blocks in a domain pool is set by 256. The bit rate calculation for different partitions of an image can be found in our previous works [6, 7, 8].

For an image partitioned into 8×8 or 4×4 range blocks, we measure the mean value and the variance of every range block. If the block variance is less than the threshold value $E_{\text{th}} = 25$, the range block is coded by its mean value. Otherwise, the range block is coded by the proposed FMC method. The rate-PSNR comparisons of the proposed FMC method for the Lena and Peppers images under different mating ratios are given Tables 1 and 2. Obviously the proposed FMC method can significant improve the image quality for the Lena image. For the Peppers image, however, the improvement is slight. The PSNR even decreases as the mating ratio $r$ is greater than 0.5. The proposed FMC method is also tested for the cases of two-level range block sizes. The numbers of domain blocks in the parent and the child levels are 256 and 64, respectively. The conditions that the parent range block is partitioned into four child range blocks can be referred our previous work [7]. Table 3 shows the simulation results for five images. Different pairs of images are mutually coded and the best rate-PSNR performance are obtained. The PSNR improvements are very significant compared with the independently-coded images except for the Peppers image, which we believe that its intra-image similarity is higher than the inter-image one.

Finally, three images are mutually coded by the proposed FMC method. Two possible mating ratios $r_{i,j}^{(1)}$ and $r_{i,j}^{(2)}$, $1 \leq i, j \leq 3$ for each image set are tested:

$$
r_{i,j}^{(1)} = \begin{cases} 
0.32, & \text{if } i = j, \\
0.34, & \text{if } i \neq j.
\end{cases}
$$

$$
r_{i,j}^{(2)} = \begin{cases} 
0.5, & \text{if } i = j, \\
0.25, & \text{if } i \neq j.
\end{cases}
$$

Table 4 shows the simulation results for three images, which are mutually coded by the proposed FMC method. Their rate-PSNR performances are still better than that of the independently coded images.

Consider the security property of the proposed FMC method based on two-level block sizes. As shown in Fig. 1(b), both the mutually encoded images are decoded together in the proposed FMC method. Figures 2(a)–2(i) show that the images are mutually reconstructed at the first, second, and the fourteenth iterations. All the three images are successfully reconstructed. However, consider the case of independently decoding of each image. Figures 3(a) and 3(b) show the reconstructed images which are self-decoded only with their own fractal codes. For the range blocks whose domain blocks are selected from the other image, the er-
rors happen and those blocks cannot be correctly reconstructed. Therefore, these blocks are greatly distorted and the reconstructed images cannot be displayed with their original quality.

4 Conclusion

In this paper, the FMC method is proposed to mutually encode and decode two or more images. The proposed FMC method can not only improve the rate-PSNR performance of image, but also provide the security that the correspondence relation among images can protect the images from illegal users. The considerable future works can be as follows: Instead of testing all possible mating ratios, determining the best mating ratios among images in an objective way can greatly reduce the encoding time. It is also worth to explore the possible applications to watermarking fractal coded images.

Acknowledgment

This research was partially supported by the National Science Council, Taiwan, under contract NSC 92-2213-E-224-047.

References


Table 1. The PSNR (in dB) comparison for the case of single block size 8 × 8 under selecting different numbers of the domain blocks from two images.

<table>
<thead>
<tr>
<th>Mating ratio</th>
<th>0</th>
<th>0.25</th>
<th>0.5</th>
<th>0.75</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena (0.223 bpp)</td>
<td>29.09</td>
<td>30.06</td>
<td>30.16</td>
<td>30.20</td>
<td>29.89</td>
</tr>
<tr>
<td>Peppers (0.252 bpp)</td>
<td>28.00</td>
<td>28.43</td>
<td>28.59</td>
<td>28.60</td>
<td>27.81</td>
</tr>
</tbody>
</table>

Table 2. The PSNR (in dB) comparison for the case of single block size 4 × 4 under selecting different numbers of the domain blocks from two images.

<table>
<thead>
<tr>
<th>Mating ratio</th>
<th>0</th>
<th>0.25</th>
<th>0.5</th>
<th>0.75</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena (0.706 bpp)</td>
<td>33.30</td>
<td>33.51</td>
<td>34.04</td>
<td>33.86</td>
<td>33.10</td>
</tr>
<tr>
<td>Peppers (0.771 bpp)</td>
<td>31.20</td>
<td>31.31</td>
<td>31.23</td>
<td>31.04</td>
<td>30.69</td>
</tr>
</tbody>
</table>

Table 3. The best rate-PSNR (in bpp and dB) results for the case of two-level block sizes 8 × 8 and 4 × 4 for different pairs of images.

<table>
<thead>
<tr>
<th>Lena (32.98/0.481)</th>
<th>Peppers (31.12/0.591)</th>
<th>Building (28.11/0.856)</th>
<th>F-16 (30.68/0.513)</th>
<th>Harbour (25.93/0.788)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4. The rate-PSNR (in bpp and dB) comparison for mutually coded three images. Here the numbers of the domain blocks for the 8 × 8 and 4 × 4 range blocks are \( N^8 = 256 \) and \( N^4 = 64 \), respectively.

<table>
<thead>
<tr>
<th>Lena (33.45/0.493)</th>
<th>Peppers (33.53/0.478)</th>
<th>F-16 (33.53/0.478)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r^{(1)}_{i,j} )</td>
<td>( r^{(2)}_{i,j} )</td>
<td>( r^{(3)}_{i,j} )</td>
</tr>
<tr>
<td>33.45/0.493</td>
<td>33.53/0.478</td>
<td>33.53/0.478</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lena (31.07/0.597)</th>
<th>Peppers (31.16/0.589)</th>
<th>F-16 (31.38/0.517)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r^{(1)}_{i,j} )</td>
<td>( r^{(2)}_{i,j} )</td>
<td>( r^{(3)}_{i,j} )</td>
</tr>
<tr>
<td>33.53/0.478</td>
<td>33.53/0.478</td>
<td>33.53/0.478</td>
</tr>
</tbody>
</table>
Figure 1. The block diagram of the proposed FMC method: (a) encoder and (b) decoder.

Figure 2. The decoded results when three images are mutually reconstructed at the first, (a)–(c), second, (d)–(f), and fourteenth, (g)–(i), iterations.

Figure 3. The decoded results when each image is independently decoded with itself fractal code: (a) Lena, (b) Peppers, and (c) F-16.