Fractal Enhancement of Decompressed Images

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Abstract

Fractal image compression successfully uses self-similarity within an image to achieve compression. By adapting fractal image compression techniques to image enhancement, an innovative new fractal technique for visual enhancement of JPEG compressed images is created. After detecting the self-similarity characteristics of a degraded JPEG image, details spoiled by quantization are enhanced using an iterative scheme and the fractal nature of the method allows resolution enhancement and fractal zooming. The effect of the scheme is an increase in the visual quality of edges in the image for almost all areas and sharp results when the image resolution is increased.

This application of fractal theory to the problem of image enhancement reveals a number of interesting avenues of investigation and promises techniques which can be used in combination with conventional methods, exploiting both self-similarity and statistical properties to achieve enhancement.

1. Background

Compression of still images with the JPEG standard [1] is important for many applications which depend on media with limited capacity. At compression ratios of up to 10 to one and sometimes higher only a small perceptual deterioration in image quality occurs. At greater compression ratios however the perceptual quality decreases rapidly due to the greater quantization of DCT frequency coefficients. Quantization causes loss of image details and blocking and consequently several techniques have been proposed to reduce these aretfacts. Primarily these have been aimed at reducing blockiness whilst attempting to retain detail [2,3].

Fractal methods provide a new potential source of image enhancement techniques. Images can be compressed using fractals by storing information about the self-similarity of an image, resulting in a fractal code which is independent of the resolution of the source image and is efficient enough to allow high compression ratios. We show here that the methods of fractal image compression may be adapted so that the self-similarity of an image can be used for image enhancement. Because of the mutli-resolution properties of fractals this method can also be used to increase the image resolution. We investigate the results for various compression ratios and find that fractal transforms, originally developed for compression, are useful for enhancement of JPEG compressed images.

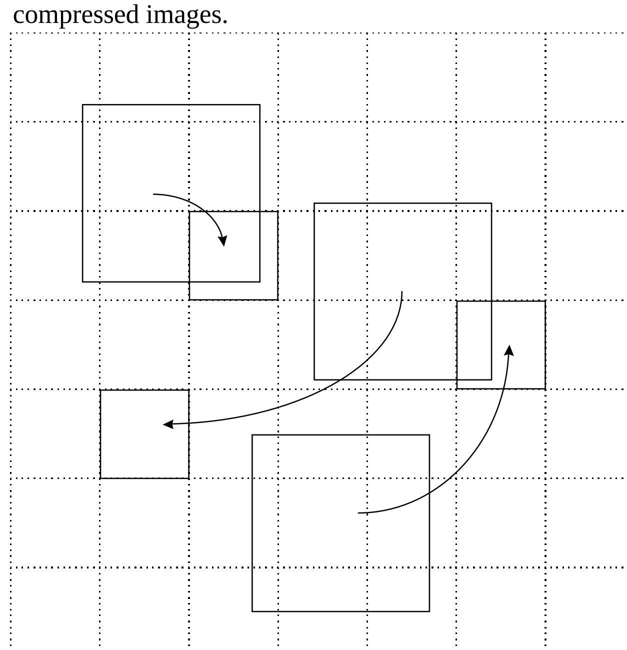

Figure 1. Some example parent and child blocks, whose relationship describes the self-similarity of the image.

2. Method

The method introduced here has two stages. Firstly the self-similarity characteristics of the JPEG image are determined using a procedure based on the encoding stage of a local search fractal transform [5-6]. Secondly an iterative procedure is applied to the image to restore frequency information lost during the quantization process.

2.1 Characterisation Stage

To characterise the image a square partition of the image is created with 8x8 pixel child blocks. For each child block *C* a 16x16 pixel parent block location is determined from all blocks of that size within a certain pixel distance of the child as illustrated by Figure 1.

To determine the location each possible parent is taken in turn, is decimated to the size of the child and has its DC component removed. The parent is then scaled to match the child as closely as possible. I.e.

$$\|C - \alpha P\| \tag{1}$$

is minimised. The parent location which gives the largest effect is chosen, so that $|\alpha|\|P\|$ is maximal. But alternatively the parent which best minimises (1) can be chosen. The result is a parent location and fractal coefficient α for each child, representing the piecewise self-similarity of the image.

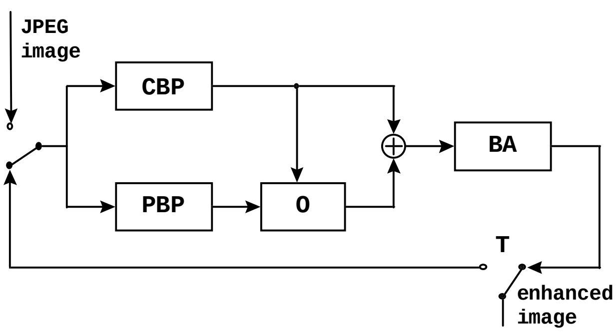

Figure 2: Operation of enhancement function. CBP - child block provider; PBP - parent block provider; O - orthogonalisation operator; BA - block assembler; T - threshold switch.

2.2 Enhancement Stage

Using the self-similarity information determined above, a function τ is defined which operates on the space of images.

For an image *x*, $\tau(x)$ is constructed by copying the original JPEG image *s* then adding fractal components. For each cell in the partition a child block *C* is taken from *s* at that location and a parent *P* is taken from *x* at the corresponding parent location. This block is contracted to the size of the child by averaging and then has its DC component and child block component removed by Gram-Schmitt orthogonalisation [7]:

$$\tilde{P} = P - \langle P, \mathbf{1} \rangle \mathbf{1} - \langle P, \tilde{C} \rangle \tilde{C} \tag{2}$$

where $\mathbf{1}$ is the matrix of 1's and $\tilde{C} = C - \langle C, \mathbf{1} \rangle \mathbf{1}$. $\langle X, Y \rangle$ denotes the inner product of image blocks.

The block $\alpha\tilde{P}$ is then the fractal component added, where α is the fractal coefficient corresponding to that child block. It should be noted that it is required that τ be a contraction mapping so that the iteration procedure described below will be convergent. Guaranteeing this property is a problem which remains largely unsolved in fractal image compression, but in practice this is not usually a cause for concern. From our experience it is reasonable to require $|\alpha| < 5$.

Enhancement of the image requires a finite sequence of iterates to be computed starting with the original image *s* and using the function τ:

$$s, \tau(s), \tau^2(s), \ldots, \tau^M(s) \tag{3}$$

The number of iterations, *M*, is chosen large enough for the sequence to effectively converge and for this purpose we use $M = \lfloor \log_2 m \rfloor$, where m is the largest child dimension. If the enhanced image is to be the same dimensions as the original then $m = 8$ and the number of iterates is 3. If decoding at higher resolutions [6] the underlying JPEG image must now be resized and the determined parent locations scaled appropriately. The number of iterations is then calculated using the above formula. The M^{th} iterate $\tau^M(s)$ is the final, enhanced version of the image.

The operation of τ is illustrated in Figure 2.

3. Evaluation

To evaluate the method we enhanced the grey-scale test images Lena, Gold Hill, Barbara 2, and Boats after compression at 10:1, 20:1, 30:1, and 40:1. We allowed a distance of 8 pixels between the centres of the parent and child and in (1) we used the L2 norm with corresponding inner product in (2).

The result was a noticeable improvement in the blurred edges and a slight reduction in blockiness in flat areas. A section of the Gold Hill result at 20:1 is shown in Figure 3. Only rarely did the fractal method reduce visual quality.

To appraise the multi-resolution properties of the method we rendered the enhanced 20:1 Gold Hill image at x2 resolution. This result is also shown in Figure 3. In this image edges are sharper and there is no extra pixelation. Finer texture has been introduced by the self-similarity mapping.

To demonstrate the compatibility of this method with algorithms for reducing blockiness we applied a very simple averaging filter at the block edges after the fractal enhancement procedure was completed. The result was a considerable reduction in blockiness and retention of sharpened edges. Figure 4 shows the results for a section of the Lena image.

To enhance an image takes about two minutes. To produce a faster method we can replace the searching part of the algorithm with the implicit fractal method presented in [4]. This results in less visual improvement than the basic method, but the algorithm is considerably faster.

4. Conclusions

We have demonstrated a method for enhancement of JPEG images which uses a fractal technique adapted from fractal image compression. The method requires no information from the original image. The method dramatically increases sharpness of edges and details. Although a small number of blocks are made worse by the procedure and the PSNR of the enhanced images compared with the uncompressed source is lower, the overall effect is an increase in the visual fidelity of JPEG compressed images in all the examples tried. In resolution enhancement the visual quality is improved and it is possible to 'zoom-in' on particular areas of an image (see [6]). We have demonstrated this method in combination with a de-blocking technique and see no reason why more advanced methods should not also be used. The fractal method providing a natural complement to conventional methods.

The primary application of this method is in improving the visual quality of compressed images, either on its own or in combination with other methods. We have demonstrated it here on images degraded by JPEG coding, but it may be adapted to work on images of various kinds. There exist many compressed images where the original is no longer available. This technique should work whenever a degradation process leaves self-similarity intact. At this stage of development this technique shows promise for use in a number of areas.

5. Acknowledgements

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6. References

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(a) (b) (c)

Figure 3. Fractal enhancement of JPEG Gold Hill image. (a) JPEG image at 20:1 compression. (b) Image after fractal enhancement. (c) Image after fractal enhancement and fractal resolution enhancement.

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(a) (b)

Figure 4. Fractal enhancement with smoothing of JPEG Lena image. (a) JPEG image at 20:1 compression. (b) Image after fractal enhancement and smoothing.