Research on Wavelet Domain Fractal Coding in Digital Watermarking

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Abstract

A novel digital image watermarking method based on wavelet domain fractal coding is presented in this paper. Employing the invariant parameters of the wavelet domain fractal transformation, we can retrieve the information embedded into the original image. In the watermarking scheme, the original collage map is altered to embed the watermark into the wavelet domain. Experiments show that the watermarking method is robust against image compression attack.

1. Introduction

Digital watermarking technology has attracted a great deal of attention in recent years, because watermarking is a good way to protect the intellectual property rights of digital media. The information carried by the watermark can be accessed using a detection algorithm with the secret key provided. An important property of a watermark is its robustness with respect to image distortions [1].

The fractal theory has proved to be suitable in the field of image coding and watermarking. Barnsley [2] [3] assumes that many objects can be closely approximated by self-similarity objects that might be generated by use of IFS transformations. Form this assumption [4], the IFS can be seen as a relationship between the whole image and its parts. Jacquin [5] [6] developed an algorithm to search a set of transformations giving a good quality to the decoded images. In recently years, IFS was used in digital watermarking. J. Puate and F. Jordan [7] presented a watermarking method based on fractal image coding of Local Iterated Function System. Their watermark algorithm consists of a coding-decoding process and retrieving the mark will be performed as a fractal coding process. Using of the invariance of relative position of affine transformation between of a range block and its matching domain block, undetectable mark was embedded in. However, experiment show that the robustness and the image quality of the scheme are not very satisfied. Yao [8] made some improvements for J. Puate and F. Jordan's method. They modified the restriction on regions of matched block searching and propose new searching regions. Unobvious improvement of robustness had been made. Patrick [9] used fractal code in DCT domain to embed watermarking. Blocks of image were transformed to DCT coefficients and fractal code was searched among DCT coefficients blocks in order to embed watermark. However, an index table was needed in retrieving scheme.

2. Fractal coding in wavelet domain

2.1. Fractal image coding

In fractal coding an image is encoded as the attractor of an IFS, it is base on the observation that natural images are partially self-transformable. The main idea of a fractal based image coder is to determine a set of contractive transformations to approximate each segment of the image with a larger one.

Let's consider a complete metric space (X,d) where d is a given metric. The elements of the space are digital images. The fractal coding procedure of x is to construct a transformation $W : X \to X$. We can call it a contractive transformation when:

$$d\big(W(x),W(y)\big) \le s d(x,y)$$
$$x,y \in X\,, \qquad 0 \le s < 1$$

In this case, exists a point x^* such that:

$$W(x^*) = x^*$$
$$\lim_{n\to\infty} W^n(x) = x^*$$

This point is called a fixed point.

An IFS consists of a complete metric space (X,d) and a number of contractive mappings W_i defined on X. The fractal transformation associated with IFS is defined as:

$$A = W(A) = \bigcup_{i=1}^{N} W_i(A)$$

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A is the attractor of IFS and transformation are usually chosen to be affine. The reason to define a set W_i is that it is difficult to construct such W directly in practical use. Once W is determined, it is easy to get the decoded image by applying transformation W iteratively on any initial image until the succession of the image does not vary significantly.

In Jacquin's practical scheme, the image is partitioned into two kinds of blocks: the Range Blocks R_i and the Domain Blocks D_i. The main idea is to search IFS relies on range blocks which are similar to the domain blocks. The affine transformation W_i applied on the domain block is contracting and luminance scaling and shifting. The affine block $W_i(D_j)$ which is most similar with the correspondent Rang Block R_i is called Matching Block and the maps is built by associating to Matching Block is called Collage Map.

2.2. Fractal coding in wavelet domain

A 2-D discrete wavelet transformation decompose the image to produce a sequence of detail images, corresponding to the horizontal, vertical and diagonal details at each of the resolution levels, and a gross approximation of the image at the coarsest resolution level. Let f_L denote the detail image at the Lth resolution level which consist of three detail images LH_L, HH_L and HL_L.

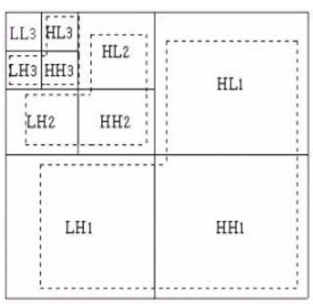


Figure 1. Detail images at each resolution level

Only one resolution level detail image f_L is chosen to process the fractal coding in order to embed the mark. The level choice of detail images will determine the invisibility and robustness of the mark. The higher the level is chosen, the more robustness and the lower invisibility is gained.

Define a metric d_{MSE} in the sense of Mean Square Error in detail images space *F*.

$$d_{MSE} = \left[\int_F \left(f(x,y) - g(x,y)\right)^2 dxdy\right]^{1/2}$$

It can be proved that *F* is a complete metric space. Let P_1 denote a partition of detail image f_L in $n \times n$ non overlapped blocks referred to as Range Block R_i. Similarity P_2 will denote another partition of f_L in $2n \times 2n$ blocks. The encoding algorithm is to establish a relationship between P_1 and P_2 in such a way that R_i can be expressed as a set of transformations to be applied on a particular D_j. The transformations we employed are contraction, Luminance Scaling and Luminance shifting. For each Range block R_i, there is a domain block D_j which is most similar (in the sense of the metric d_{MSE}) to R_i excepting itself. A vector V_i has its origin in R_i and points to the correspondent D_j which becomes the Matching Block $\hat{R}_i$. A luminance scaling and shifting transformation W_i will apply on the D_j.

$$\hat{R}_i = W_i(D_j) = t_i D_j + o_i.$$

Where t_i denote the luminance scale and o_i is the luminance offset.

Then the fractal code of detail image in wavelet domain will consist of Matching blocks defined with the V_i and luminance transformation W_i. The associating map of the code is called a collage map.

If $W = \bigcup_{i=1}^{N} W_i$ is the fractal transformation of the Lth level detail image f_L, f'_L is the restored detail image. That is

$$f'_L = \lim_{K \to \infty} W^K(f_0)$$

Then f'_L is the attractor of the IFS and it is easy to retrieve form the code by applying transformation W iteratively on any initial image f_0 until the succession of the detail images does not vary significantly. We can obtain that

$$W(f'_L) = W\left(\lim_{K \to \infty} W^K(f_L)\right) = f'_L.$$

That is to say that employing the invariant parameters of the fractal transformation, we can retrieve the information embedded into the original image form the retrieve one.

3. Embedding and detection of watermark

Our watermarking method uses the fractal code which is generated by calculating an IFS from the image. Employing the invariance of the IFS code, the mark can be hidden and retrieved. In order to greatly improve the robustness and image quality we will coding coefficients of one resolution level detail image in wavelet domain and embed the mark into. Our algorithm adds artificial and visually invisible local similarity into detail image in wavelet domain. This is done by substitution the range block R_i with a new Matching Block in stead of original best one. In other words, the watermark is embedded altering the original collage map with a new one which controlled by the watermark. Watermark embedding we proposed consists of a coding-decoding process and the mark retrieving will be performed as a fractal coding process also.

3.1. Watermark embedding

Watermarking embedding scheme consists of coding-decoding process:

The host image will be transformed into the wavelet domain firstly. We perform the *L*th level discrete wavelet decomposition of the host image. The second level detail image f_L are selected process the fractal coding in order to embed the mark. Search K Matching Blocks $\{\widehat{R}_{i1}, \widehat{R}_{i2}, ..., \widehat{R}_{iK}\}$ in sense of metric d_{MSE} for each Range Block R_i instead of only one Matching Block. These Matching Blocks sets are called Matching Pools.

$\{W_{i1}, W_{i2}, ..., W_{iK}\}$ which is defined with luminance scale $\{t_{i1}, t_{i2}, ..., t_{iK}\}$ and luminance shifting $\{o_{i1}, o_{i2}, ..., o_{iK}\}$ are the correspondent transformation of Matching Pool $\{\widehat{R}_{i1}, \widehat{R}_{i2}, ..., \widehat{R}_{iK}\}$. And $\{V_{i1}, V_{i2}, ..., V_{iK}\}$ are the vectors pointing the domain blocks D_j which become the elements of Matching Pools. The mark is embedded by substitute the best Range Block R_i with a new block in Matching Pool. This substitution is controlled by the watermark S which is generated from the copyright owner's key as follows:

$$S = \{s_1, s_2, ..., s_M\}, s_i \in \{-1, 1\}$$

Where it is a mean of zero binary pseudo-random sequence of length *M*. *M* Match Pools are selected to embed the watermark based on minimize d_{MSE} between selected match pool and its correspondent range block. A threshold of d_{MSE} determined which Matching Pool is selected to embed the mark.

The Range Blocks is coded by Matching Pools with rules as followed:

- If $s_i = 1$, then R_i is coded by $\hat{R}_{ik}$. k satisfies $t_{ik} = \max(t_{i1}, t_{i2}, ..., t_{iK})$.
- If $s_i = -1$, then R_i is coded by $\hat{R}_{ik}$. k satisfies $t_{ik} = \min(t_{i1}, t_{i2}, ..., t_{iK})$.
- Other R_i which correspondent match pool is not selected is coded by $\hat{R}_{i1}$ the best match blocks.

An IFS code of the detail image coefficients can be obtained, which consist of pointers V_i and luminance transformations W_i (defined by t_i and o_i).

Then the decoding is performed with fractal coding describe above. The result detail image of wavelet domain contains the watermark and the watermarked image obtained after an inverse wavelet transformation.

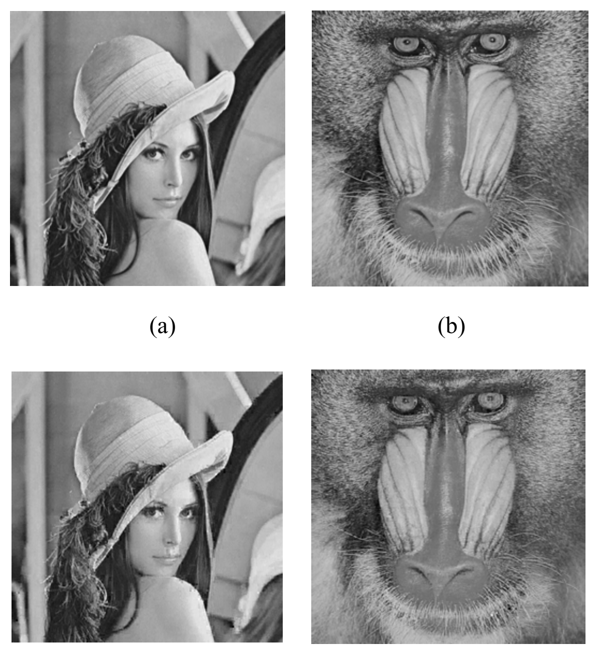
3.2. Watermark detection

In the proposed watermark detection scheme, copyright is determined based on the presence or absence of the watermark without the original image. The test image is transformed into wavelet domain and the second level detail image is selected to perform fractal coding. The Matching Pool $\{\widehat{R}_{i1}, \widehat{R}_{i2}, ..., \widehat{R}_{iK}\}$ of each range block is constructed. Match blocks in each match pool are arranged by increasing of MSE.

The rule to decide if a range block has been signed with a zero to a one, is the following one:

- If $t_{i1} <$ mean $\{t_{i1}, t_{i2}, ..., t_{in}\}$, then 1 is embedded.
- If $t_{i1} >$ mean $\{t_{i1}, t_{i2}, ..., t_{in}\}$, then -1 is embedded.

To make final decision, the Similarity is calculated between retrieved marks S^* and S using the correlation function. Whether the watermark is present or absent is determined based on the Similarity compared with a threshold *T*.



(a) (b) (c) (d)

Figure 2. The original image and the watermarked image. (a) Original Lena (256×256), (b) Original Balloon (256×256), (c) watermarked Lena (PSNR=32.84dB), (d) watermarked Balloon (PSNR=29.01dB)

4. Experimental results

We use images Lena (256×256) and Baboon (256×256) as the original image, shown in Fig. 2 (a) and (b). The watermarked image is presented as Fig. 2 (c) and (d) for case n=4, L=2 and Match Pool size K=10. Comparing with Jordan's and Yao's results, Test results show that the method we proposed greatly improved imperceptibility of the watermarked images. The result of Jordan's method presents a PSNR of 25.40dB (for case Lena, eighth iteration) whereas that of our method is equal to 32.84dB. Fractal coding in wavelet domain greatly improved quality of the watermarked images.

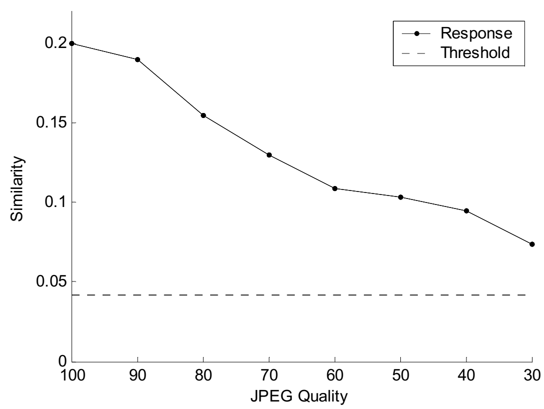


Figure 3. Similarity in Lena image after JPEG compression

We compressed the watermarked image Lena with different quality factors, the test results are shown in Fig. 3. We can see that the results are very good until quality factor equal to 30% and the responses are higher than the threshold. The robustness to JPEG compression is due to fractal coding in wavelet domain.

5. Conclusion

In this paper, we present a novel digital image watermark scheme based on fractal coding-decoding and wavelet transformation. Host images are transformed into wavelet domain firstly and propriety level detail images are selected to embed the watermark. We employ fractal coding-decoding in the coefficients of detail images in wavelet domain and construct match pools for each range block. The one which is to code the range block in Match Pool is controlled by the watermark. Experiments have been performed in order to measure the robustness of the scheme against image compression attack. Finally, fractal coding in wavelet domain extracts several other parameters that might also be used to sign the image.

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