Color Image Embedding using Multidimensional Lattice Structures

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Abstract

This paper describes a robust data embedding scheme which uses noise resilient channel codes based on a multidimensional lattice structure. Compared to prior work in digital watermarking, the proposed scheme can handle a significantly larger quantity of signature data such as gray-scale or color images. A trade-off between the quantity of hidden data and the quality of the watermarked image is achieved by varying the number of quantization levels for the signature, and a scale factor for data embedding. Experimental results on signature recovery from JPEG compressed watermarked images show that good quality reconstruction is possible even when the images are lossy compressed by as much as 85%. Potential applications of this method include, in addition to watermarking, digital data hiding for security and for bit stream control and manipulation.

Keywords: digital watermarking, data hiding, color image processing, multidimensional lattice structure

1 Introduction

Digital watermarking is one approach to protecting the rights on the digital media while not being too obtrusive [1,2,3]. For example, a digitally watermarked image is obtained by invisibly hiding signature information into the host image. The signature is only recoverable by the owner who has the key to decoding the hidden data.

Most of the existing watermarking techniques use pseudo-random sequences or binary images as signature data. The quantity of the data that could be embedded is quite limited by the embedding methodology used. Typically embedding is done in the frequency domain as it provides a spatially distributed signature which is perceptually not obvious in the watermarked image. In addition, frequency domain fusion appears to be more robust than spatial domain approaches proposed in the literature in terms of signature recovery under compression or other signal processing operations.

Some recent papers have considered data hiding in color images [4,5]. Kutter [4] proposes an amplitude modulation scheme where in signature bits are multiply embedded by modifying pixel values in the blue channel. The blue channel is chosen as the human visual system is less sensitive to blue than other primary colors. Also, changes in regions of high frequencies and high luminance are less perceptible, and thus are favorable locations for data embedding. Robustness is achieved by embedding the signature several times at many different locations in the image. Fleet *et al* [5] propose an embedding scheme using the S-CIELAB, a well-known standard for measuring color reproduction errors. They embed amplitude-modulated sinusoidal signals into the yellow-blue color band of an opponent-color representation scheme.

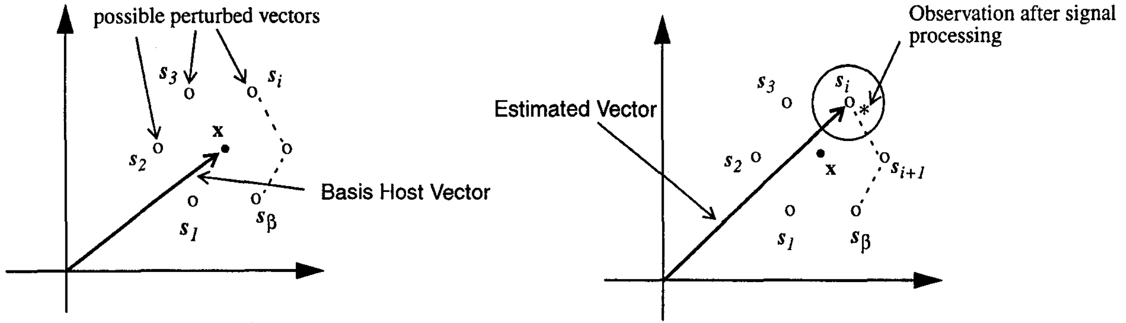
This paper extends our previous work on embedding larger amounts of data [6,7], such as gray scale images, into a host image. In particular, we propose an approach for fusing color signature images in larger color images using wavelet transforms and lattice structures. We use the YUV color space for representing color. The Y component is the luminance part of the signal, and U and V represent the chrominance components. Adopting the YUV color space facilitates a simple extension from images to digital video such as those in the MPEG format. The U, V components are down-sampled by a factor of two.

In the proposed method the host and signature images are first wavelet transformed. The discrete Haar wavelet transform is used. The wavelet coefficients are then encoded using channel codes derived from a finite subset of the lattice structure [8,9,10], which consists of all integer N-tuples with constraints. As the quantity of embedded data increases, higher order shells of the lattice structure are included in the channel code to accommodate them. Results are presented wherein the signature data is a color image of size one quarter of the host image. As the results demonstrate, there are no visible distortions in the watermarked images and signature recovery is possible even with 85% lossy JPEG compression. The following sections describe the data embedding method and some experimental results are provided.

2 Data Embedding

2.1 Lattice Structures

If the original host image is available, the operations of data injection and retrieval are, in fact, very similar to the channel coding and decoding operations in a typical digital communication system. Channel coding refers to the gamut of signal processing done before transmission of data over a noisy channel. When the watermarked image is compressed or modified by image processing operations, this is equivalent to adding noise to the perturbed coefficients. The



(a) Possible perturbations

(b) Estimation from received noisy vector

Figure 1: Basic lattice structure and embedding methodology. (a) Possible β-ary perturbed lattices in a basis host vector. (b) Possibly noisy vector positions of original perturbed lattice s_i after signal processing operations.

retrieval operation subtracts the received coefficients from the original ones to obtain the noisy perturbations. The true perturbations that represent the injected data are then estimated from the noisy data as best as possible.

In this work, we adopt a vector-based approach to hidden data injection [8,9,10,11]. We group N transform coefficients to form an N-dimensional vector, and modify it by smaller N-dimensional vectors that represent the channel codes. The motivation for using vector perturbations as opposed to scalar perturbations follows from the realization that higher dimensional constellations usually result in lower probability of error for the same rate of data injection and the same noise statistics.

Figure 1 shows the basic concept of the perturbation vector in the host N-dimensional vector space. In Figure 1, 'x' represents a host vector in an N-dimensional space. To embed data from an β-ary source with symbols $\{s_1, s_2, \ldots, s_\beta\}$, we perturb the original vector so that the perturbation coincides with one of β corresponding channel codes. The perturbed vector is denoted by one of the 'o's in the Figure 1 depending on the particular source symbol it represents. After the watermarked image has undergone compression or other transformations, a perturbed vector representing, for example symbol s_i in the diagram, may be received as a noisy vector '*' in Figure 1 (b). It is then an estimation problem to extract the transmitted symbol from the vector received. Assuming an additive Gaussian noise model, the received vector is decoded as representing the symbol whose channel code it is closest to in Euclidean distance.

2.2 Embedding/Extracting Data

The human visual system is not very sensitive to changes in the higher frequency spectrum, and as such many of the lossy compression techniques rely on saving bits needed to represent the information in these higher frequencies. For this reason it is important that the signature data be embedded in the lower frequency components of the host data.

A schematic of the embedding procedure is shown in Figure 2. The basic hiding/extracting scheme is similar to the our previous data hiding/extracting technique using the multidimensional lattice structures [7]. A single level of discrete wavelet transformation (DWT) [12] of both the host and the signature image is made before data embedding. Each coefficient of the signature image is quantized into β levels. In order to embed the quantized coefficient information, a set of N coefficients in the host image is grouped to form an N-dimensional vector, and the vector is then perturbed according to a β-ary channel code consisting of a subset of the lattice scaled by a factor α. If $\vec{v}$ represents a vector of host DWT coefficients after grouping, and the index of the quantized signature coefficient is i, then the perturbed vector $\vec{w}$ is given by:

$$\vec{w} = \vec{v} + \alpha \cdot \vec{C}(s_i) \qquad (1)$$

where $\vec{C}(s_i)$ represents the channel code (subset of the lattice structure) corresponding to the symbol s_i.

In signature recovery, the watermarked DWT coefficients

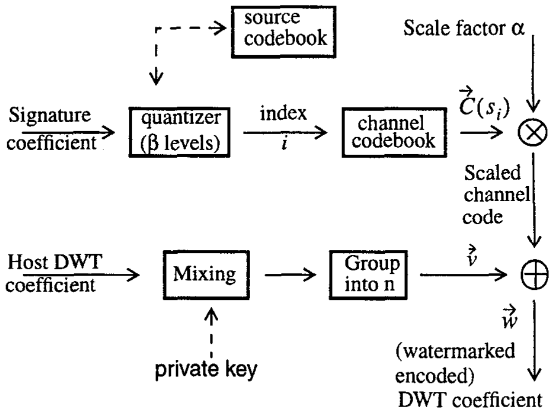


Figure 2: Encoder in the Embedding Procedure

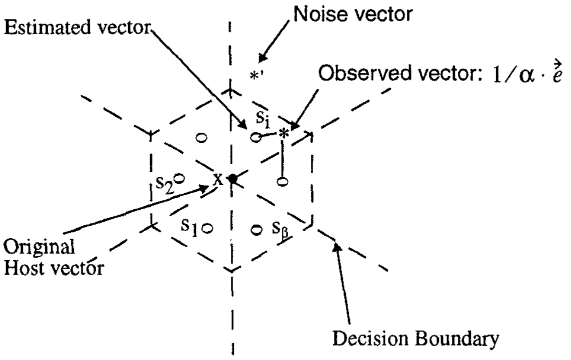


Figure 3: Determining the closest vector from the observed vector within each shell perturbed lattice points.

are grouped based on the β-ary channel code used in encoding to obtain a new vector $\vec{e}$. This is then scaled by the factor $1/\alpha$ where α is as defined in (1). The resultant vector $1/\alpha \cdot \vec{e}$ is then nearest-neighbor encoded to find the index i of the channel code nearest to it in the Euclidean distance. In particular, we find an index i such that:

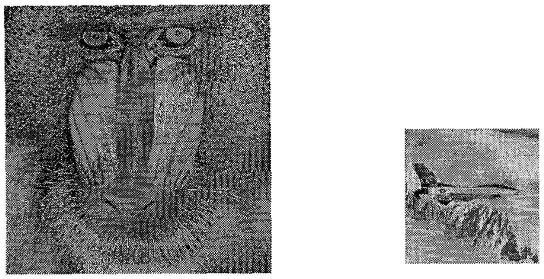
$$\left\|\vec{C}(s_i) - \frac{1}{\alpha}\vec{e}\right\|^2 \le \left\|\vec{C}(s_j) - \frac{1}{\alpha}\vec{e}\right\|^2, \quad \forall j \in \{1, 2, \ldots, \beta\} \qquad (2)$$

where the $\vec{C}(s_i)$ s refer to the β code-vectors in the channel codebook. From the index i, the quantized DWT coefficient can be obtained.

This is illustrated in Figure 3. Assume that the symbol s_i was sent but because of compression or some other image processing operation, the observed vector '*" (equal to $1/\alpha \cdot \vec{e}$) is obtained. If '*' is within the triangualr decision boundary shown, s_i will be correctly estimated. Obviously the scale factor α controls the extent of the regions around each s_i. A large scale factor can tolerate a large perturbation at the expense of a degradation in the watermarked image quality.

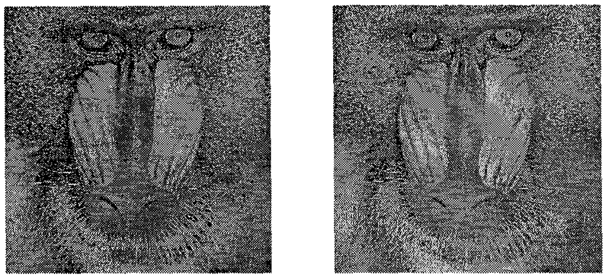
3 Experimental Results

Figure 4 shows an sample. All color images are represented in the YUV color space. Figure 4(a) shows a 256x256 color image and Figure 4(b) shows a 128x128 gray scale signature. The signature is injected into the Y component of the transform coefficients of the host image. Figure 4(c) shows an 81% JPEG compressed watermarked image using 32 channel codes and Figure 4(d) shows the same compressed image using 144 channel codes. Note that there are no visible distortions in the watermarked images. Figure 4(e) and Figure 4(f) show the recovered signatures for the two quantization levels. The reconstructed images are of very good quality for authentication purposes.



(a) Host (256x256)

(b) Signature (128x128)



(c) α=15, 81%, β=32

(d) α=15, 81%, β=144

(e) α=15, 81%, β=32

(f) α=15, 81%, β=144

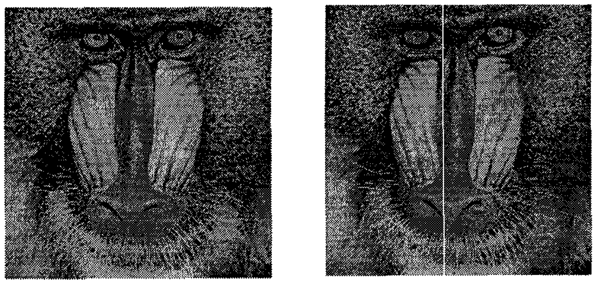
Figure 4: (a) Host color imae, (b) Gray-scale signature image, (c)(d) Watermarked and JPEG lossy compression images at two different quantization levels. (you can see color images in the CD-ROM proceeding), and (e), (f) recovered images.

Figure 5 shows an example of a color signature embedding. The entire signature data is embedded in the Y component of the host data in order not to distort the color in the watermarked image. For this reason, the size of the signature image is less than that for a gray scale embedding. Another example of image embedding is shown in Figure 6. This method can be easily extanded to video watermarking as well.

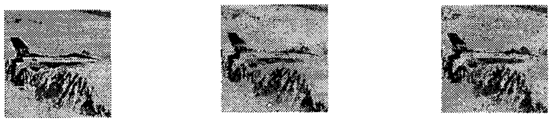
Figure 7(a) shows the similarity of the reconstructed image to the original signature image for various levels of JPEG compression. A normalized similarity function $S(s)$ is defined as

$$S(s) = \frac{\hat{s}^t s}{(\hat{s}^t \hat{s})(\hat{s}\hat{s})} \qquad (3)$$

when s is the signature image components organized as a vector, and $\hat{s}$ is the reconstucted signature vector. As can be



(a) α=15,81%, β=32 (b) α=15,81%, β=144



(c) Signature (color, 100x100) (d) from (a) (e) from (b)

Figure 5: (a),(b) Watermarked and lossy compression using images. (c) signature image, (d),(e) recovered imags. (see color images in the CD_ROM proceeding).

seen from the graph, the watermarked image can be easily authenticated even at 85% lossy JPEG compression. Figure 7(b) shows Peak Signal to Noise Ratio (PSNR) of the reconstructed image as a function of JPEG compression factor. The PSNR is computed with respect to the original signature beofre quantization. Note that good quality reconstruction is possible upto about 75% JPEG compression for α=15.

4 Conclusions

We have presented a scheme for gray-scale and color image embedding using multi-dimensional lattice structures in the DWT domain. The scheme presents a framework for a more structured digital watermarking schemes, aimed at embedding large amounts of data into a source. In contrast with most current approaches to watermarking, the proposed method enables embedding a significant amount of signature data. In our experiments, we have demonstrated the feasibility of embedding gray scale and color images into a host image with very little perceptual distortion. The signature images can be recovered under lossy compression as well. Besides watermarking, this method is suitable for applications such as image data hiding wherein smaller images can be transmitted using larger host images.

Acknowledgments

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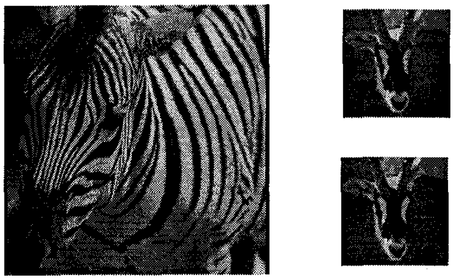
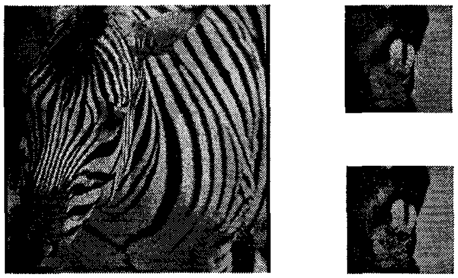
(a) Host (512x512)



(b) Signature (204x204)

(d) from (c)

(c) Watermarked α=15, 81%, β=32



(f) Signature (204x204)

(g) from (e)

(e) Watermarked α=15, 81%, β=32

Figure 6: Another example of color image embedding

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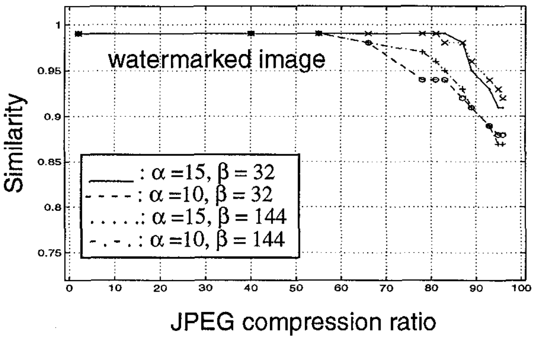
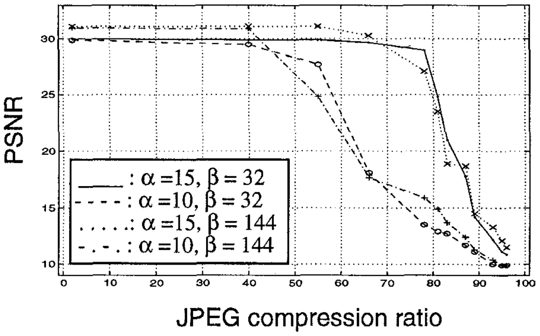


(a) Similarity measure



(b) PSNR results

Figure 7: The similarity and PSNR results for the host and signature images shown in Figure 4.

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