A New Fast Robust Color Image Watermarking Method using FPCA Clustering

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***Abstract*— There is a generally–accepted tendency to consider and process color images as a set of parallel gray–scale planes (instead of an ensemble of a 3–D realization). Although, even now, many researchers make the same assumption, but it is proved that using vector geometries leads to more promising results. In this paper, by processing the color images as vector geometries, a novel method is proposed to decompose a natural image into three eigenimages. Based on the proposed eigenimage extraction method, a new color image watermarking method is proposed. Experimental results show that the proposed watermarking method is highly resistant to the subsequent probable attacks while it is also very fast.**

I. INTRODUCTION

Watermarking the artworks is attracting more attention because the possibility of electronic storage and transmission makes the probability of piracy extensively more [1]. Some researchers work on methods for general–purpose digital data watermarking (*e.g.*, [2], [3]). These approaches do not use the problem–specific constraints and possibilities. Also, as watermarking has a very tight relation with the cryptography, some researchers try to solve both problems at once (*e.g.*, see [2], [4]). Here, we separate these two different approaches of finding some perceptually non–important places in the image for embedding some data, and to encrypt that data.

Since the birth of the watermarking concept, many researchers have worked on the redundancy of natural images in the spatial domain, resulting in high performance spatial watermarking techniques (for a comprehensive survey look at [1]). Although, some researchers have worked on data hiding using the color redundancy (*e.g.*, see [3]), but small work has been performed on finding the real redundant color data in the image. Generally, researchers work on some subjectively–investigated assumptions about the color channels [3], [5], [6]. For example in [3] the researchers add the watermark to the *blue* plane and in [6] the authors use the $CIE-Lab$ color space in a quantization framework to add the color watermark in the least significant bits.

Recently, much attention is focused on using the *principal component analysis* (PCA) for processing color images [7]. This new approach, assumes color images as vector geometries and applies vectorial tools on them. This is in contrast with the general assumption about the performance of considering color images as a set of parallel grayscale images or using standard color spaces for working on them (*e.g.*, see [8], [9], [10], [11]). It is proved that a PCA–based color descriptor called *linear partial reconstruction error* (LPRE) is a proper model for homogenous color swatches [12]. Also, the comparison of the LPRE–based fuzzification and homogeneity measurement has proved its performance over the commonly used *Euclidean* and *Mahalanobis* distance–based approaches [13]. *Abadpour* and *Kasaei* used the LPRE idea to develop a cylindrical clustering method called the *fuzzy principal component analysis–based clustering* (FPCAC) [14]. Comparison of FPCAC with the well–known *fuzzy C–means* FCM [15] have proved that FCM results in meaningless segments in color images, while the results of FPCAC are desirable [14]. In this paper, we propose a new color image watermarking method using a new method proposed to extract three eigenimages from a color image. the method uses the FPCAC method [14].

II. PROPOSED METHOD

Assume that the color image I and the grayscale watermark signal W are given. Firstly, we propose to feed I into the FPCAC clustering algorithm [14]. Now, the pixels of I are categorized into c classes with the crisp membership maps denoted as $K_i, i=1,\cdots,c$. Assume producing the sets,

$$\varphi_i=\left\{\vec{I}_{xy}|K_{ixy}=1\right\}, i=1,\cdots,c. \tag{1}$$

Now, φ_i contains the color vectors in the i–th cluster. As the clusters are cylindrical [12], the members of each φ_i set can be described using lower dimensional representations (note that $Rank(\varphi_i)=3$). Denoting the expectation vector of φ_i as $\vec{\eta}_i$ and its PCA matrix as C_i, each member of φ_i can be translated into PCA coordinates as,

$$\vec{c}'=C_i^{-1}(\vec{c}-\vec{\eta}_i). \tag{2}$$

To reach to these PCA coordinates for all pixels, each pixel in the image must be processed using the parameters of the cluster to which it belongs. We propose computing,

$$\vec{I}_{1xy}=\sum_{i=1}^{c}K_{ixy}C_i^{-1}(\vec{I}_{xy}-\vec{\eta}_i) \tag{3}$$

Now I_1 is a three channel image containing the eigenimages of the original image. Denote the three channels of I_1 as i_1, i_2, and i_3. Computing σ_{i_1}, σ_{i_2}, and σ_{i_3}, we can estimate the energy compaction of the proposed eigenimage extraction method. In the same manner with [16] we propose to compute,

$$\kappa_j = \frac{\sigma_{i_j}^2}{\sigma_{i_1}^2 + \sigma_{i_2}^2 + \sigma_{i_3}^2} \tag{4}$$

for $j = 1, 2, 3$. Now, κ_j shows the energy content of the j–th eigenimage. Note that we have,

$$\kappa_1 + \kappa_2 + \kappa_3 = 1. \tag{5}$$

As proved in [12] for homogenous sets (like φ_i) neglecting the third principal component or adding proper amount of data to it, and then reconstructing the data back, produces no artifacts while preserving the objective quality of the image. In this way, we propose computing,

$$\vec{I}_{Wxy} = \sum_{i=1}^{c} K_{ixy}(C_i I_{2xy} + \vec{\eta}_i) \tag{6}$$

where I_2 is a three channel image with its first and second channels as I_1 while its third channel contains the watermark signal or is left blank. To prevent disturbing the visual appeal of the image after watermarking, the watermark signal is scaled to fit the energy range of the third channel. Denoting the third channel as i_3 and the watermark signal as W, this is performed using,

$$\tilde{W} = \frac{\sigma_{i_3}}{2\sigma_W}(W - \eta_W). \tag{7}$$

Assume the watermarked image I is given and we are going to extract the (probable) watermark from it. The watermark extraction process contains computing I_1 as (3) and normalizing the third principal channel (i_3) as,

$$\tilde{i}_3 = 255\frac{i_3 - \eta_{i_3}}{\sigma_{i_3}}. \tag{8}$$

Many times the extracted watermark is visible but further increase if the contrast makes it more appropriate specially when it is needed to print the result or show it in low–quality monitors.

III. EXPERIMENTAL RESULTS

The proposed algorithms are developed in *MATLAB 6.5*, on a *2800 MHz*, *Pentium IV*, personal computer with 256MB of RAM. Figure 1 shows some of the test images used for analyzing the performance of the proposed method. These images are *Lena*, *Peppers*, and *Mandrill*, all 512×512 uncompressed TIF format files in RGB color space. Figure 2 shows the sample watermarks used in this study. All watermarks are grayscale 512×512 uncompressed TIF images acquired from the logos of academic institutions around the world.

Figure 3 shows the eigenimages extracted by the proposed method from the standard images shown in Figure 1 when setting $c = 5$. Each eigenimage is normalized to span the $[0, \cdots, 255]$ interval. To obtain a numerical analysis of the proposed eigenimage extraction method, the same test is performed on each sample image for each value of c in the $[1, \cdots, 10]$ interval. As the proposed clustering method contains some levels of non–repeatability, each experiment is performed ten times and the average values are used. Figure 4 shows the time needed to extract the eigenimages (t_1) and the time elapsed when reconstructing the image from its eigenimages (t_2). Figure 4–a shows that, the time needed to extract the eigenimages of a given image have an almost quadratic relation to the number of clusters c ($t_1 \propto c^2$). Also, Figure 4–b demonstrates that reconstructing and image from its eigenimages elapses proportional to the number of clusters ($t_2 \propto c$). In the worst case ($c = 10$) computing the eigenimages lasts less than one minute while reconstructing the image takes less than five seconds.

Fig. 1. Sample images.

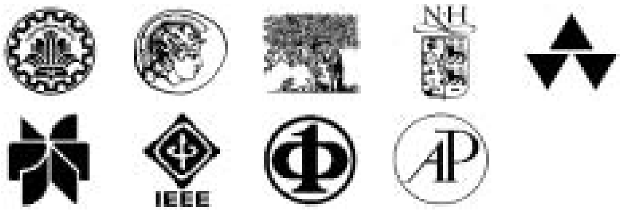


Fig. 2. Sample watermarks.

Figure 5 shows the values of κ_1, κ_2, and κ_3 in each image with each value of c. In this way, Figure 5 shows the compaction of the energy in the three eigenimages. The case of $c = 1$ corresponds to computing the eigenimages using the PCA in the entire image as a whole. This obvious case is about 10% worse than the cases produced by selecting values of c larger than unity. Note that selecting $c \neq 1$ switches the method from PCA to local PCA. In all cases, selecting values of c larger than 5 shows negligible change in the energy spread pattern between eigenimages, while almost tripling the elapsed time. This experiment along with others performed on other images proves that $c = 5$ is an ideal compromise.

In this paper, we use the eigenimages to embed data in a color image. Thus, it is essential to estimate the ratio of information lost when neglecting an eigenimage or replacing it with the watermark signal. Figure 6 shows the values of PSNR when reconstructing the sample images while neglecting the third eigenimage. Figure 7 shows the PSNR values when replacing the third eigenimage with the watermark data (watermarking the image). In the watermarking test the watermark image shown in Figure 2–a is used. Figure 6 shows that

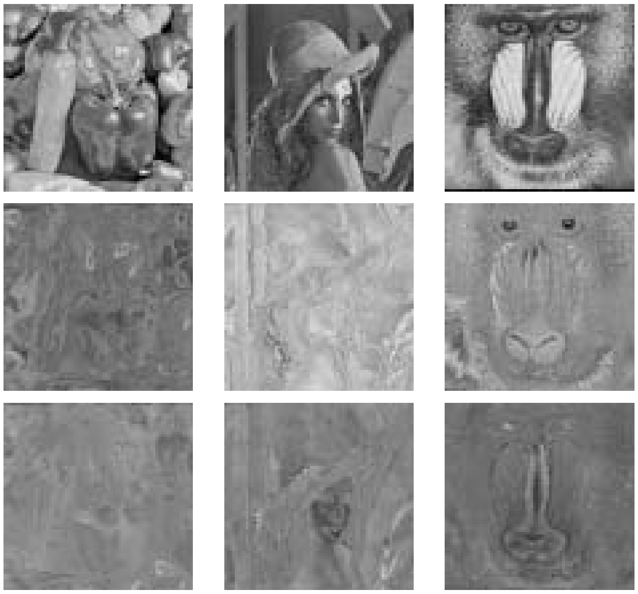
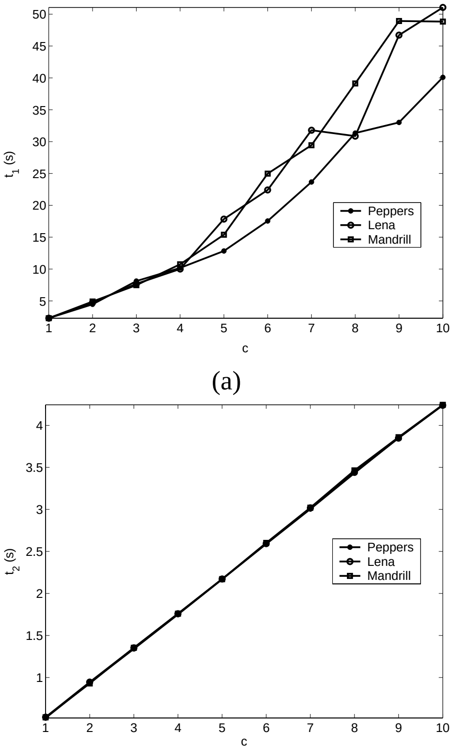


Fig. 3. Eigenimages extracted from sample images using the proposed method.



(a)

(b)

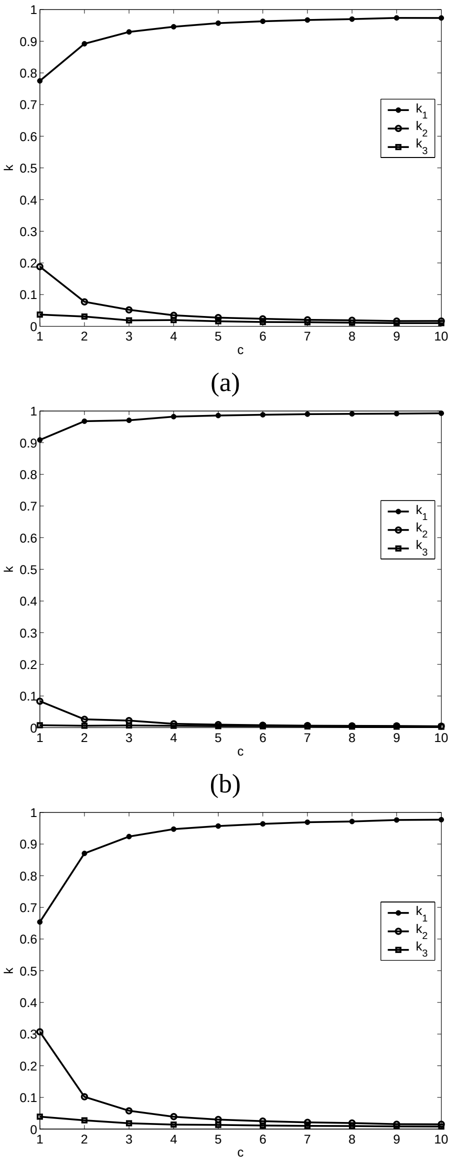
Fig. 4. Elapsed times by the proposed method. (a) Extracting the eigenimages. (b) Reconstructing the image.

neglecting the third eigenimage results in PSNR value of more than $25dB$. Also, the choice of $c = 5$ is reasonable here, because the main rise of the PSNR curve happens when $c \leq 5$. Comparing Figure 7 and Figure 6 shows that embedding the watermark results in an averagely $2dB$ decline in the PSNR, while again the PSNR is higher than $25dB$ in this test. In other tests the same range of PSNR is observed but sometimes the watermarked image shows higher PSNR when compared to the image produced by neglecting the third eigenimage. Figure 8 shows the results of neglecting the third eigenimage and Figure 9 illustrates the case of replacing it with the watermark data shown in Figure 2–b. In these tests the value of c equal to 5 is used. Figure 10 shows the extracted watermarks from the images shown in Figure 9 and Figure 11 shows the exaggerated difference between the images shown in Figure 9 and the original images shown in Figure 1. Investigating figure 11 shows where the method embeds the data; at each pixel, the direction of the third principal component shows the direction in which data can be placed while not affecting the visual appeal of the image.

An experiment is conducted to test the sensitivity of the method to the proper selection of c. the watermark signal is embedded into the sample images using $c = c_1$ and then the extraction process is performed using values of $c = c_2 \neq c_1$. Figure 12 shows a typical set of results when $c_1 = 5$ and $c_2 = 1, \cdots 9$. The embedded watermark is distinguishable in all cases. Thus, there is no need to know the exact value of c used for embedding the watermark to an image to extract the watermark from it.

To test the robustness of the proposed watermarking method against invasive attacks, the watermarked images are attacked by some methods using the *Adobe Photoshop 6.0*. Figure 13 shows some of the attacked watermarked images and figure 14 shows the corresponding extracted watermarks. The attacks include rotation, scaling, translation, adding text, blurring, artistic effects (*plastic wrap* and *lens flare*), adding noise ($PSNR = 25dB$), geometrical distortion, JPEG compression ($20 : 1$), and color distortion. The watermark image is highly distinguishable in all samples shown in Figure 14. Investigating figure 14 along with the other numerous tests shows that the proposed watermarking method is robust against linear and nonlinear geometrical transformations including rotation, scaling, cropping, and other geometrical distortions. Also, it is robust against occlusion, artistic effects, captioning, noise addition, enhancement operations like brightening and increasing contrast (even when performed locally), lossy compression, frequency domain filtering, and different kinds of blurring.

Table I compares the proposed watermarking method with the best methods available in the literature. The table lists the watermark capacity of each method when embedding to a 512×512 color image along with the domain in which data is embedded. Also, the attack resistance of different approaches is compared here. It is observed in different experiments that the standard deviation of pc_3 in a typical image is more than 8. Thus, using the proposed watermarking method on a 512×512 color image at least a same–sized $2bpp$ image can be used as the watermark signal (2 comes from $\log_2 \frac{8}{2}$). This makes the watermark capacity of the proposed method equal to 64KB. This is four times more than the highest capacity of the available approaches (the method by *Barni et. al.* [17]). The



(a)

(b)

(c)

Fig. 5. Energy compaction of the eigenimages. (a) *Peppers*. (b) *Lena*. (c) *Mandrill*.

only approaches using the color vectors are proposed by *Chou et. al.* [6] and *Piyu et. al.* [4]. Note that, the method by *Chou et. al.* [6] is the only method showing resistance to the linear point operations like brightening and contrast enhancement. It must be emphasized that their method's resistance is limited to the global such operations, while our proposed method is resistant even to local linear point operations. Unfortunately, no attention is spent on non–linear geometrical operations like elastic and perspective transformation and image editing processes like adding text, artistic effects, occlusion and so on. While many copyrighted images are used in books, posters, and websites where they appear with some levels of artistic manipulation, the non–efficiency of the available watermarking literature in dealing with these attacks is a real shortcoming.

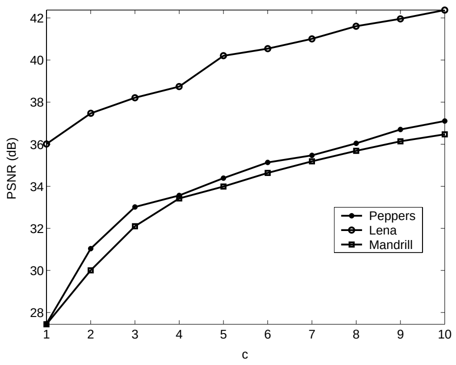


Fig. 6. PSNR values for different number of clusters when neglecting the third eigenimage.

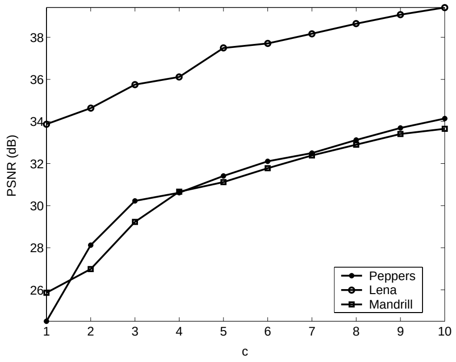


Fig. 7. PSNR values for different number of clusters after watermarking.

Table I depicts that the proposed method is the only available method resistant to the seven groups of attacks listed in its caption.

Recently a robust watermarking method is proposed for color images. *Abadpour et. al.* proposed a different method for extracting the eigenimages using bi–tree decomposition. The method contains interpolation of various 2–D functions and produces some block artifacts. Although, the method in [16] shows the same robustness as the proposed method, but it elapses about 10 minutes on embedding or extracting the watermark to/from an image.

IV. CONCLUSIONS

A new FPCA–based watermarking method is proposed that uses the color redundancy in an image to embed a same–sized gray–scale image into it. The experimental results show that,

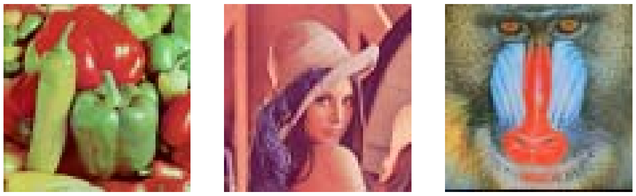


Fig. 8. Results of neglecting the third eigenimage.

TABLE I

Comparison of different watermarking methods with the proposed method used in a 512×512 image. –: Not Resistant. $\sim$: Partially Resistant. $\surd$: Completely Resistant. [Abbreviations: Cap: Capacity, G: Grayscale, SCC: Single Color Component, CV: Color Vector, LG: Linear Geometrical Transformation, NLG: Nonlinear Geometrical Transformation, LPO: Linear Point Operations, NLPO:Nonlinear Point Operations, SO: Spatial Domain Operations, EO: Editing Operations, CMP: JPEG Compression].

Method	**Cap.**	**Domain**	**Attack Resistance**						
			LG	NLG	LPO	NLPO	SO	EO	CMP
[18]	$4KB$	G	$\sim$	–	–	–	–	–	$\surd$
[19]	$8KB$	G	$\surd$	–	–	$\sim$	$\sim$	–	$\surd$
[20]	$8KB$	G	$\sim$	–	–	$\sim$	$\sim$	–	$\surd$
[6]	$2KB$	CV	$\sim$	–	$\sim$	$\sim$	$\sim$	–	$\surd$
[3]	$1KB$	SCC	$\sim$	–	–	$\sim$	$\sim$	–	$\surd$
[17]	$16KB$	SCC	$\surd$	–	–	$\sim$	$\sim$	–	$\surd$
[21]	$8B$	SCC	–	–	–	–	–	–	$\surd$
[22]	$0.5KB$	G	$\surd$	–	–	$\sim$	$\sim$	–	$\surd$
[23]	$60B$	G	$\surd$	–	–	–	$\sim$	–	$\surd$
[24]	$64B$	G	$\sim$	–	–	–	$\sim$	–	$\surd$
[4]	$2KB$	CV	$\sim$	–	–	$\sim$	$\sim$	–	$\surd$
[16]	$64KB$	CV	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$
Proposed	$64KB$	CV	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$

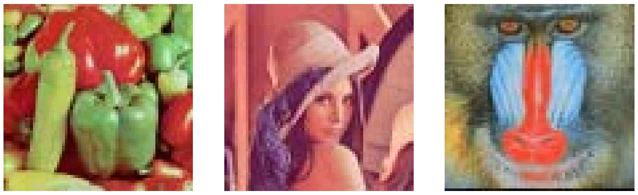


Fig. 9. Results of the proposed watermarking method.

Fig. 10. Watermark signals extracted from images shown in Figure 9.

while the method gives high values of PSNR and no subjective artifact, it is highly resistant against invasive attacks. The method performs promisingly when dealing with attacks in the spatial domain (linear and non–linear geometrical transformations), the color domain (manipulating the contrast, brightness both globally and locally), and frequency domain (filtering and blurring). The total time needed for embedding or extracting the watermark is less than one minute. To the best knowledge of the authors no watermarking method with such robustness is available in the literature.

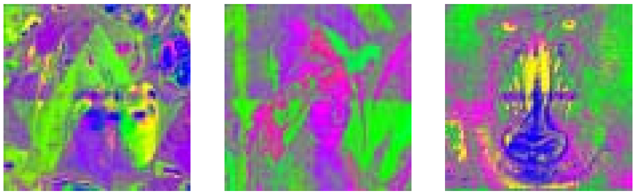


Fig. 11. Exaggerated difference between original images shown in Figure 2 and watermarked images shown in Figure 10.

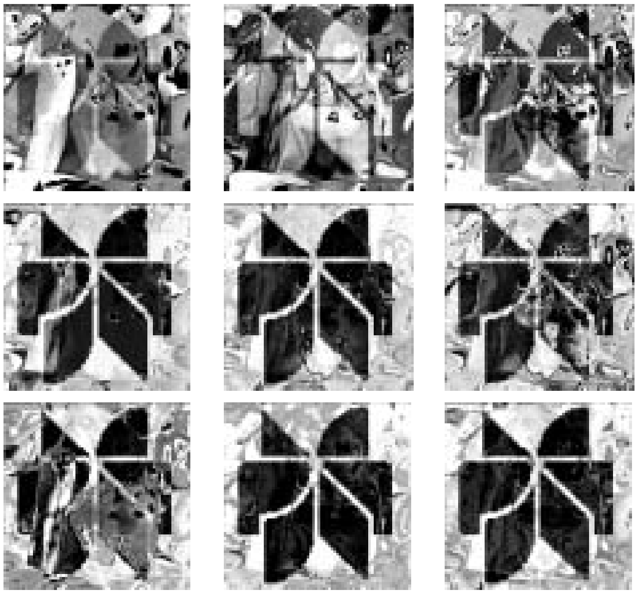


Fig. 12. Results of extracting the watermark using values of $c = 1, \cdots 9$. The actual watermarking is performed using $c = 5$.

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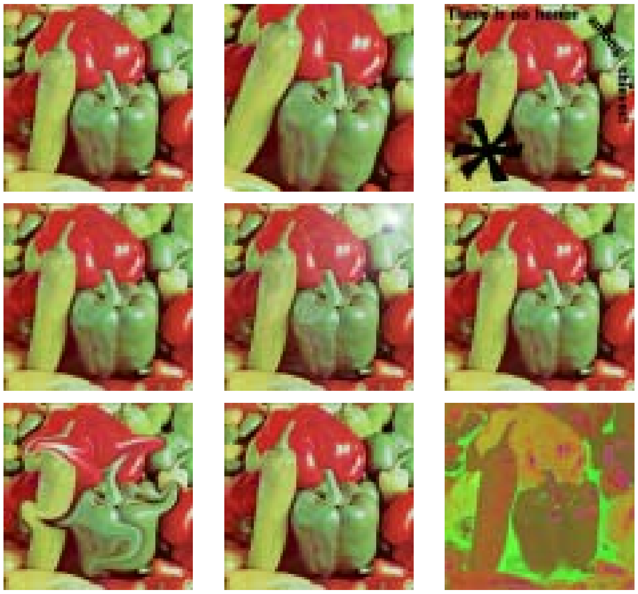

Fig. 13. Attacked watermarked images.

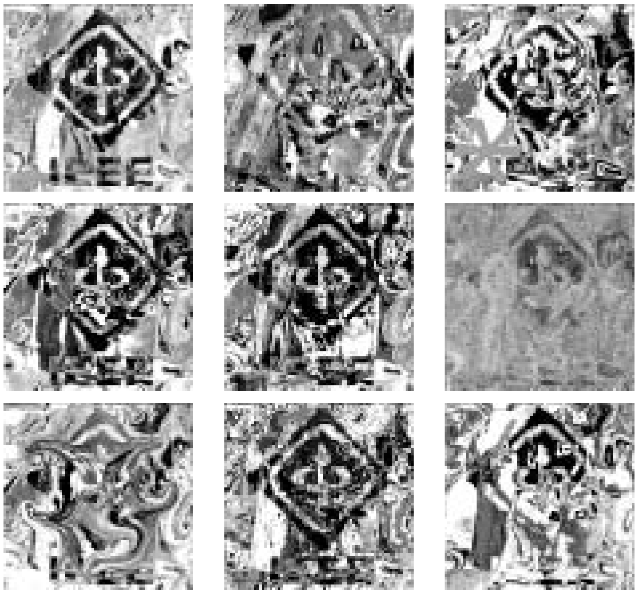

Fig. 14. Extracted watermarks from the attacked watermarked images shown in Figure 13.

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