Scalar Quantization Based Robust Multiple Image Watermarking

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ABSTRACT: *With respect to the general information hiding problem, a tradeoff is involved between robustness, visibility and capacity. Security of digital multimedia content has become an important issue for content owners and service providers. As watermarking is identified as a major technology to achieve copyright protection. There are many watermarking techniques for data hiding and each of them has some advantages and disadvantages. The robust method for data hiding is embedding the hidden data in the choice of quantizer for the host data. A quality factor is determined to get an appropriate quantization matrix. To modify the bit streams directly during embedding cause unacceptable distortions to cover images. We had developed DCT based entropy Threshold method which determines threshold for each block and only those blocks are selected for whose entropy exceeds by a predetermined threshold for embedding the data. The experimental results show that the proposed scheme has good imperceptibility.*

Keywords: DCT, Entropy, Scalar-quantization, Watermarking, JPEG

Received: 6 March 2010, Revised 29 March 2010, Accepted 7 April 2010

1. Introduction

The availability of digital data such as multimedia services on the internet leads to exponential growth of multimedia traffic (image, text, audio, video, etc). With the ease of editing and perfect reproduction in digital domain, the protection of ownership and the prevention of unauthorized tampering of multimedia data become important concerns. Digital watermarking has been proposed as a generic technique to solve various problems associated in the area of Digital Right Management (DRM) and multimedia security. Watermarking is defined as the practice of imperceptibly altering a work to embed a message about the work [1]. JPEG compressed images are fit for information hiding for its fixed block structure. Images are usually compressed before transmission. Therefore, information hiding in compressed JPEG images is a good choice. If we embed more than one watermark in the cover image to increase the robustness, then it is also termed as multiple watermarking techniques [2, 3]. These are broadly classified as composite, segmented and successive (Re-watermarking).

A variety of practical approaches to data hiding with a focus on scalar quantization schemes and shows that these schemes are superior to spread spectrum hiding schemes [4, 5, 6, and 7] which simply add a spread version of the hidden data to the host. To limit the distribution while embedding watermark, the watermarking scheme must use image-adaptive criteria in addition to statistical criteria. The use of local criteria to choose where to embed the watermark can provide robustness against a variety of attacks [8].

The rest of this paper is organized as follows: section II explains the scalar quantization based techniques in detail. Section III gives the terminology used in the paper. Section IV gives the proposed technique. The experimental results are given in the section V. The paper is concluded in section VI followed by the references.

2. Terminology

This section describes the basic principle of JPEG encoding process. The baseline of JPEG encoding process can be separated into several phases, such as DCT, quantization, zigzag scan. Firstly using two-dimensional DCT the host image is transformed into the 8x8 block data unit, after which most of the block intensity is packed into only a few top-left coefficients [9]. DCT-based watermarking is based on two facts. The first is that much of the signal energy lies at low-frequency sub-bands containing the most important visual parts of the image. The second is that high frequency component of the image can usually be removed through compression and noise attacks. The watermark is therefore embedded by modifying the coefficients of the middle frequency sub-band so that the visibility of the image will not be affected at the same time the watermark cannot be removed by compression [11]. Quantization is defined as division of each DCT coefficient by its corresponding quantizer step size, followed by rounding to the nearest integer: In this step the less important DCT coefficients are wiped out. This (lossy) transformation is done by dividing each of the coefficients in the 8x8 DCT matrices by a weight taken from a quantization table. If all weights are equal the transformation does nothing but if they increase sharply from origin, higher spatial frequencies are dropped quickly. A zigzag scan is applied to the coefficients to obtain a sequence, which includes leading low frequencies and useless high frequency values followed. Because the DC coefficients (Top left coefficient) of neighboring 8x8 block data units are large. That invariant property for JPEG images is utilized in selecting the image's feature vector. JPEG allows for some flexibility in the different stages, not every option is explored. Also the focus is on the DCT and quantization. The values in the quantization table are not the part of JPEG standards. Each application must supply its own, allowing it to control the loss compression tradeoff. Implementation of JPEG is given below:

- The image is partitioned into 8x8 blocks of pixels
- Working from left to right , top to bottm the DCT is applied to each block
- Each block is compressed using quantization
- Coding is applied for zig zag scanned coefficients [12]

Most existing compressors start from a sample table developed by the ISO JPEG committee. Subjective experiments involving the human visual system have resulted in the JPEG standard quantization matrix. With a quality level of 50(Table-1), the matrix renders both high compression and excellent decompressed image quality [10]. The importance of the coefficients is dependent on the human visual system; the eye is much more sensitive to low frequencies.

$\mathbf{Q}_{50}$ =

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Table 1. Quantization Matrix with Quality Factor 50

If however, another level of quality and compression is desired, scalar multiplies of the JPEG Standard quantization matrix (QM) may be used. For a quality level greater than 50 (less compression and higher image quality), the standard QM is multiplied by (100-quality level)/50. For a quality less than 50 (more compression, lower image quality), the standard QM is multiplied by 50/quality level. The scaled QM is then rounded and clipped to have positive integer values ranging from 1 to 255. For example, the following QM yields quality levels of 10(Table-2) and 90(Table-3).

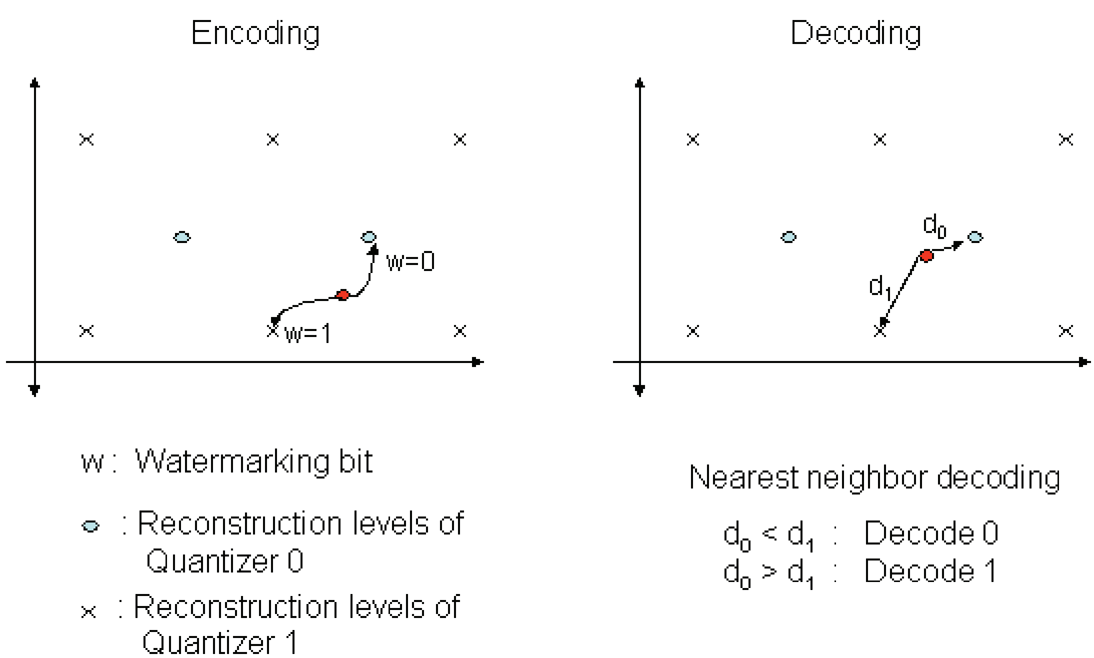
$$
Q_{10} = \begin{bmatrix}
80 & 60 & 50 & 80 & 120 & 200 & 255 & 255 \\
55 & 60 & 70 & 95 & 130 & 255 & 255 & 255 \\
70 & 65 & 80 & 120 & 200 & 255 & 255 & 255 \\
70 & 85 & 110 & 145 & 255 & 255 & 255 & 255 \\
90 & 110 & 185 & 255 & 255 & 255 & 255 & 255 \\
120 & 175 & 255 & 255 & 255 & 255 & 255 & 255 \\
245 & 255 & 255 & 255 & 255 & 255 & 255 & 255 \\
255 & 255 & 255 & 255 & 255 & 255 & 255 & 255
\end{bmatrix}
$$

Table 2. Quantization Matrix with Quality Factor 10

$$
Q_{90} = \begin{bmatrix}
3 & 2 & 2 & 3 & 5 & 8 & 10 & 12 \\
2 & 2 & 3 & 4 & 5 & 12 & 12 & 11 \\
3 & 3 & 3 & 5 & 8 & 11 & 14 & 11 \\
3 & 3 & 4 & 6 & 10 & 17 & 16 & 12 \\
4 & 4 & 7 & 11 & 14 & 22 & 21 & 15 \\
5 & 7 & 11 & 13 & 16 & 12 & 23 & 18 \\
10 & 13 & 16 & 17 & 21 & 24 & 24 & 21 \\
14 & 18 & 19 & 20 & 22 & 20 & 20 & 20
\end{bmatrix}
$$

Table 3. Quantization Matrix with Quality Factor 90

Quantizers, or a sequence of quantizers, can be used to as appropriate-identity functions to embed the watermark information. The number of possible values of m determines the number of required quantizers. Index is m that selects the quantizer that is used to represent m. For the case $m = 2$ we have a binary quantizer. The following figure illustrates the QIM information embedding process. To embed one bit m, m {1, 2}, and image pixel is mapped to the nearest reconstruction point representing the information of m *(Figure-1)*



(a) (b)

Figure 1. (a) Watermark Embedding Process (b) Watermark Extraction Process

The minimum distance min d between the sets of reconstruction points of different quantizers in the ensemble determines the robustness of the embedding,

$$d_{\min} = \min_{(i,j);i\neq j} \min_{(x_i,x_j)} \left\| s(x_i;i) - s(x_j;j) \right\|$$

Intuitively, the minimum distance measures the amount of noise that can be tolerated by the system.

3. Proposed Method

In this paper, a new method of multiple watermarking based on spread transform is proposed, which has good performances in validity and capacity. This section presents a multiple watermarking method based on spread transform, in which the watermark is embedded in the DCT block based on the predefined threshold of the entropy or the energy of the block. In this section the embedding and extraction methods of watermarking are introduced, and its performances are analyzed.

3.1 Watermark embedding method

Firstly, the DCT is applied in blocks of 8 × 8 pixels

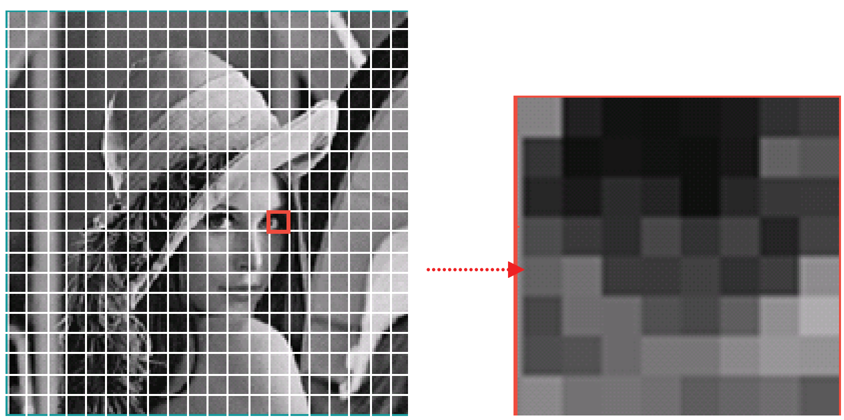


Figure 2. DCT Applied to Lena Image

Now find the entropy of each 8*8 block. Entropy is a statistical measure of randomness that can be used to characterize the texture of the input image. Entropy is defined as -sum (p.*log (p)).

- The embedding of the watermark is done in only those blocks for which the threshold exceeds predefined value of the energy or entropy. This step achieves additional compression lossless by encoding the quantized DCT coefficients more compactly based on their statistical characteristics.
- Consider for example Lena (512*512) grayscale image. If the threshold for entropy is set to 5.65, we get block nos. 1321, 1330, 1396, 1464, 2716 having entropy greater than 5.65. The entropy for these blocks is 5.7188.
- These highest threshold blocks are selected for embedding of watermark as it indicates that these blocks are having the most important information of the cover image. Hence the security is increased in case of filtering or compression attacks. However, if we choose the lowest entropy blocks for selection, then we get the improved quality of watermark image but it will not resist the filtering or the compression attacks. Hence, we had preferred the highest entropy blocks for embedding to increase the security against attacks.
- The watermark is now segmented into parts to embed into different entropy selected blocks. The division of watermark for simplicity is considering into four parts here.
- Performing the DCT on the entropy qualified blocks, a simple piecewise division by the quantization matrix obtains the quantized matrices needed for the next step. The design QF determines the maximum JPEG compression that hidden image will survive.
- For example, a sample 8*8 block containing DCT coefficient is shown below

1543.9	135.4668	5.8419	12.5184	-13.6250	-1.2017	-2.5551	-0.6298
12.7812	-0.9245	-7.1464	-18.0999	13.2450	0.0626	0.3727	-0.5799
-1.0476	-1.0958	-0.5152	10.6682	-0.3943	0.1639	-0.7134	0.9762
-6.7837	-0.5256	11.1829	-15.0425	24.7901	-1.0519	0.0658	-0.5516
-8.8750	-0.0678	0.8959	0.5789	0.6250	0.9882	-0.7770	0.4963
0.8599	-0.4944	-0.6568	0.6856	-0.3482	0.1482	-0.1245	-0.6292
-0.2426	-0.2790	0.5366	-0.3367	0.0280	0.8188	0.0152	1.0106
0.2648	0.1576	0.5886	0.5410	0.9137	-0.0539	-0.2442	-0.1812

Table 4. Original 8*8 DCT Coefficients

- Consider QF=75 the quantization table for QF=75 is shown below

8	6	5	8	12	20	26	31
6	6	7	10	13	29	30	28
7	7	8	12	20	29	35	28
7	9	11	15	26	44	40	31
9	11	19	28	34	55	52	39
12	18	28	32	41	52	57	46
25	32	39	44	52	61	60	51
36	46	48	49	56	50	52	50

Table 5. Quantization Table with QF=75

- Let M_{ij}^{QF}= quantization matrix entries for particular QF where i, j $\in$ {0, 1, 2, ……,, 7} and QF = 100 corresponds to best quality image..

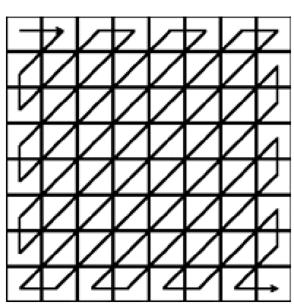
$$\tilde{c}_{i,j} = \frac{c_{i,j}}{M_{i,j}^{QF}} \quad \forall \ \text{i, j} \in \{0,1,2,..,7\}$$

- So we get following matrix

192.99	22.578	1.1684	1.5648	-1.1354	-0.060085		
2.1302	0.15408	1.0209	1.81				
-0.14966	-0.15654	-0.0644					
-0.9691	-0.0584						
-0.98611							

Table 6. Quantized Coefficients

- Scan these DCT coefficients in the zigzag order as shown below



0	1	5	6	14	15	27	28
2	4	7	13	16	26	29	42
3	8	12	17	25	30	41	43
9	11	18	24	31	40	44	53
10	19	23	32	39	45	52	54
20	22	33	38	46	51	55	60
21	34	37	47	50	56	59	61
35	36	48	49	57	58	62	63

DC : DC coefficient AC : AC coefficient

Table 7. (a) zig- zag fashion (b) positions of quanitized coefficients

- The coefficient with zero frequency in both dimensions is called the “DC coefficient” and the remaining 63 coefficients are called the “AC coefficients.”

- The coefficients $\tilde{c}_{i,j}$ are scanned in zigzag fashion to get one dimension vector $\tilde{c}_k$ where $0 \leq k \leq 63$.

  $\tilde{c}_k$ = [192.99 22.578 2.1302 -0.14966 0.15408 1.1684 1.5648 1.0209 -0.15664 -0.9691 -0.9861 -0.0584 -0.0644 1.81 -1.1354 -0.060084]

- The first n of these coefficients are used for hiding after excluding the DC coefficient (k = 0) term. Thus, low frequency coefficients are used for embedding.

- Quantize these coefficient values $\tilde{c}_k$ to nearest integers and take their magnitude to get r_k.

  r_k = [23 2 0 0 1 2 1 0 1 1 0 0 2 1 0]

- Consider the binary watermark b. we add dither to this watermark using random dithering. Dither is an intentionally applied form of noise used to randomize quantization error, preventing large-scale patterns such as “banding” (stepwise rendering of smooth gradations in brightness or hue) in images. Random Dithering is a method of dithering which produces monochrome (black and white) images. Random Dithering works by choosing a different random value for each pixel in the image. If the pixel is more intense (usually a higher number) than the random value, it becomes white, if not, it becomes black.

- Using random dithering(also known as dither quantization), the hidden coefficients $\tilde{d}_k$ are given as

$$\tilde{d}_k = \left\{ \begin{array}{ll} Q_{bl}(\tilde{c}_k), if\, 1 \leq k \leq n \\ \tilde{c}_k \qquad ,otherwise \end{array} \right\}$$

Where, bl is the message and Q_{bl} is the quantizer Q0 or Q1 depending upon the message, bl $\in$ {0, 1} is incoming bit that determines which one of two quantizers $Q_1(\bullet)$ and $Q_0(\bullet)$ is used.

- So the resulting matrix after embedding the watermark is shown below:

1543.9	132.000	0	16	0	0	-2.5551	-0.6298
12.00	0	-7.000	-20.000	13.2450	0.0626	0.3727	-0.5799
0	0	0	10.6682	-0.3943	0.1639	-0.7134	0.9762
-7	0	11.1829	-15.0425	24.7901	-1.0519	0.0658	-0.5516
0	-0.0678	0.8959	0.5789	0.6250	0.9882	-0.7770	0.4963
0.8599	-0.4944	-0.6568	0.6856	-0.3482	0.1482	-0.1245	-0.6292
-0.2426	-0.2790	0.5366	-0.3367	0.0280	0.8188	0.0152	1.0106
0.2648	0.1576	0.5886	0.5410	0.9137	-0.0539	-0.2442	-0.1812

Table 8. Watermarked Coefficients

3.2 Watermark extracting method

The watermarking extraction process of the watermark embedding process is the exactly reverse process of the method.

- The coefficients in $\tilde{d}_k$ are scanned in zigzag order to form an 8X8 matrix.

$$\left\{ \tilde{d}_{i,j} \right\}_{i,j}^{8} = 1$$

- The coefficients having value greater than threshold value is multiplied by JPEG quantization matrix to dequantize the coefficients.

- Inverse DCT of $\left\{ d_{i,j} \right\}_{i,j}^{8} = 1$ yields the hidden image intensity values $a'_{i,j}$ for that block.

4. Experimental Results

This multiple watermarking technique is implemented using MATLAB 7.0. The watermark is embedded in the DCT block based on the predefined threshold of the entropy of the block. Grayscale images are used as the cover works, and binary images are used as the watermark signals. Firstly, the DCT is applied in blocks of 8 × 8 pixels. The entropy or energy of each 8X8 block is calculated. The decision of where to embed the watermark will totally base on the entropy of the individual block. A predefined threshold is considered to embed the watermark. Only those blocks whose entropy is more than this threshold will be considered for embedding. Finally, different watermark information is embedded into the corresponding qualified blocks. The minimum distance decoding method described above is used as the watermark extracting method.

Many experiments are carried out under different cover images and different entropy threshold. Due to limited space, we only give the experimental results when using Lena image as the cover work (as shown in Fig).

(a) (b) (c)

Figure 3. (a) Cover Image, (b) Watermark1, (c) Watermark2

The corresponding watermarked image after applying the technique is shown below along with the extracted watermarks.

(a) (b) (c)

Figure 4. (a) Extracted watermarked image, (b) Watermark1, (c) Watermark2

The bit error ratio obtained for the corresponding watermarks are compared with the corresponding quality factors. The corresponding PSNR values are given in the table which shows that the perceptual quality of the watermark image is good. We had used the two quantization step size as 34 and 40. The bit error ratio at various JPEG quality factor (Q) is given in the following table:

JPEG quality factor (Q)	Quantiza-tion step size	PSNR	Bit error ratio (watermark-1)	Bit error ratio (watermark-2)
50	34	43.2723	0.6836	0.9072
	40	41.9346	0.6836	0.9063
75	34	43.34	0.6836	0.9036
	40	41.9346	0.6836	0.9063

Table 9. Robustness Test against JPEG

From the experimental results obtained in table1, we can conclude that the proposed algorithm is robust against the JPEG attack. The perceptibility of the cover work is intact after applying the watermarks and JPEG compression.

The quality of watermarked and attacked images is evaluated by peak-signal-to-noise-ratio (PSNR). The watermark robustness under several attacks is evaluated by bit-error rate (BER). The watermark robustness by the average BER is evaluated for all test images.

After some signal processing operation extracted Lena Image and watermarks are shown in Figure 2. This scheme can extract the watermark effectively and based on the extracted watermark the scheme suppress self noise that results in the improvement of the quality.

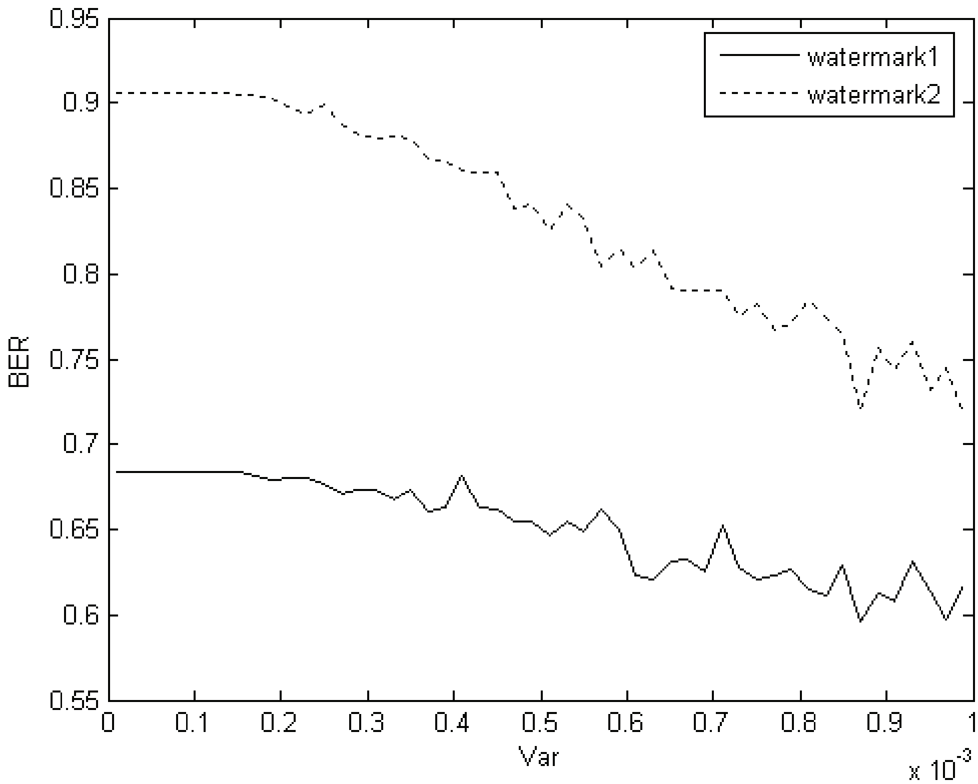


Figure 5. Bit Error Ratio of both Watermarks against Quality factor

The proposed method is tested on several grayscale images of various sizes and can be extended to color images also. The main objectives are to provide image authentication and robustness against various attacks. The embedded watermark is distributed in the transformed coefficients in such a way that it does not causes perceptual artifacts. The quality of the watermarked image is not affected even though it provides localization at pixel level. The PSNR Lena image shows that the system is successful in hiding the watermark information without making noticeable changes in the original image. Protection against JPEG compression attack is a major issue for authentication and localization schemes. In the proposed system, the robustness against JPEG compression attack is achieved by applying a predefined threshold for embedding the watermark.

5. Conclusion

We propose a framework for hiding large volume of data in images while incurring minimal perceptual degradation. The embedding of the watermark is done in only those blocks for which the threshold exceeds predefined value of the entropy. This step achieves additional compression lossless by encoding the quantized DCT coefficients more compactly based on their statistical characteristics. The local criterion to decide where to embed data gives the choice for scalar quantization without compromising robustness. The proposed method is very clear and its mathematical background is very clear. The new method can avoid many drawbacks of existing multiple watermarking methods. It can be designed to be robust or fragile watermarking algorithms accordingly, and the capacity of each watermark is the same as the common singular watermarking algorithms. Without disturbing the sensitive coefficients the framework achieve good quality image without compromising robustness.

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