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New Multi-Domains Image Watermarking Method Based on Multi-Watermarks Embedding and Neural Network Segmentation

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Abstract

The need for a robust method that protects owner rights against unintended or malicious stealing, which has arisen because of the rapid increase of Internet data exchange and multimedia use, in addition to international electronic commercial services and the multimedia that it contains, has become a substantial constraint to the research in this domain. This paper proposes a novel method for image watermarking based on embedding multiple identical watermarks in different domains of the image representation: i.e. spatial and DCT domains, without any distortion of the watermarked image. In the spatial domain, the processing method uses a non-linear neural network segmentation to output the different zones of watermark embedding with respect to the image characteristics. Basing on this study, we compute the appropriate variable embedding gain factors chosen within the limit of the perceptibility threshold. However, in the DCT domain, different DCT blocks coefficients are selected with respect to the JPEG table quantization values in the middle frequency band in order to decrease the image distortions and increase the watermark robustness. Fifteen watermarks are created and embedded in these two domains in order to take advantage of both spatial domain robustness (i.e. against different asynchronous attacks), and DCT domain robustness (i.e. against jpeg compression and some other distortions). After different STIRMARK attacks, experimental results show that the proposed method is robust against several synchronous and asynchronous image attacks such as filtering, lossy compression, rotations, etc. The well-chosen locations of the different recurring embedded watermarks with variable gain factors in addition to the studied selection of the used DCT coefficients where the watermarks are coded proved that all or some watermarks totally survive to the specific attacks. A study detailing the robustness of the proposed algorithms and the computed distortions is also presented. The simulation results are compared with different well-known algorithms to outline the robustness and the supremacy of the proposed method.

Keywords: Image watermarking, Neural network segmentation

I. INTRODUCTION

A wide range of distributed imagery and digital media are manipulated, copied or redistributed, without any consideration to the proprietor rights [5, 19]. In addition, considerable financial losses are inflicted on manufacturers because of the facility to reproduce or falsify digital media. To provide copyright protection [9] and prove owner rights [12], watermarking is an efficient way. It eliminates these disagreeable manipulations and protects the intellectual properties rights of multimedia contents [20]. On the other hand, a watermarking method needs to satisfy the equilibrium between three major constraints: robustness against various attacks, imperceptibility and high capacity of watermark embedding [11, 15]. Among the expansion of the image processing technologies, the attacks against watermark methods become progressively more complicated. They can be sorted out in two different classes. The first is the synchronous attacks that do not modify the image's pixel position, the information is attached to the image pixel that can be distorted or spread into the pixels neighbor but the essential information stays attached to the original pixel. The compression or the noise adding belongs to this kind of attack. The second class of attacks contains the asynchronous attacks. They modify the pixel position and cause information to move through the image. The non-synchronization resulting from such attacks requires specific watermarking techniques. All the geometrical attacks belong to this class [6]. In fact, a vital factor that defines watermarking method efficiency is its robustness against intentional or malicious image processing attacks. The watermark should survive a large set of manipulations, or become damaged in the same way as the image. On the other hand, watermark imperceptibility is crucial to the image integrity and content preservation [23]. The third important factor that makes a watermarking method commercially interesting is its ability to embed a bigger amount of data in the image [23]. By embedding in a specific domain of the image representation, we exploit the robustness that offers this domain against specific kinds of distortions. The embedded watermark can be subjected to various intentional or unintentional attacks and it must resist to them with high performances. In this paper, we propose to exploit the robustness of both spatial and frequency domains at the same time. A set of identical watermarks is embedded in the DCT frequency domain [1] in different selected coefficients with respect to the JPEG quantization table and in a chosen way to minimize the vulnerability of the embedding scheme by the redundancy of the multiple embedded watermarks [3]. At the same time, a second set of watermarks is embedded in the spatial domain. A preliminary study based on neural network segmentation is carried out in order to determine the best embedding locations and the highest usable gain factor in each of the determined zones. The gain factor variation is relative to the change of the image zones characteristics. This embedding approach proves that the watermarked image becomes more robust against a wide range of synchronous and asynchronous image processing attacks rather many other watermarking methods. In addition, because of the recurrence resulting from the identical multiple embedded watermarks in these two domains, all or some of these inserted watermarks survived in each of the applied attacks. The STIRMARK tools [17, 18] generate all these attacks. This paper is organized as follows: In section 2, an overview of the spatial DCT and DWT watermarking domains is presented. Section 3 details the proposed multi-embedding method in the spatial and DCT domains. In section 4, we illustrate the robustness of this technique against different STIRMARK attacks, and we test its capacity to detect the embedded watermarks via several simulation results. The advantages of embedding multiple identical watermarks in different domains using neural network segmentation and the simulation results are also detailed.

II. THE PROPOSED MULTI-EMBEDDING METHOD IN THE DCT AND SPATIAL DOMAINS:

2.1. Watermarks presentation:

The watermarks are presented as identical binary images. Each one contains the same data about the authors, research unit and the university name, with $P \times P$ size described as follows:

$$W_L = \{W_L(i,j), 0 \leq (i,j) \leq P\},\ W \in \{0,1\},\ andL \in \{1,2,....,L_max\} \quad (1)$$

W_L denotes the binary watermark; L is the watermark index that varies from one to the maximum number of the watermarks having to be inserted. Let I_h be the host image used to be watermarked in the spatial and frequency domain with size $= M \times M$, P is chosen equal to 32 and L_max is set as equal to 7 in the frequency domain and 8 in the spatial domain.

2.2. DCT watermark embedding:

The first step of the proposed method is to use the frequency domain in which multiple and identical watermarks are embedded. Let IDCT be the transformed image in the DCT domain presented as an (8×8) DCT blocks. The DCT coefficients where the watermark bits are encoded are chosen from the medium frequency band of the transformed blocks in order to provide additional resistance to lossy ocompression while avoiding significant modifications or distortions to the cover image. Instead of choosing arbitrarily the coefficients locations, we can increase the robustness to compression by basing our choice on the recommended JPEG table as indicated below in Table 1. In fact, if two locations are chosen because they present identical quantization values, any scaling of the first coefficient will scale the second by the same factor preserving their relative size [24]. Furthermore, to augment survival chances of the embedded watermarks against a wide range of attacks and reduces the probability of detection error; we make use of an additional gain factor denoted K in the watermark embedding process. This gain factor represents the watermark embedding strength, more this factor is high more the watermark becomes robust against attacks. Nevertheless, a constraint is applied on the choice of its value. In fact increasing this gain must not alter the image quality or introduce a change on its appearance or content. The variation of this gain must be limited by the first changes that begin to appear on the image called imperceptibility threshold. Some criteria are presented for the choice of K as shown in equation (5), but in the proposed study, a code is performed to compute the gain factor value in order to respect the imperceptibility threshold shown by the image distortion based on the Weber's law. It is found that the computed gain value is approximately equal to this introduced by the following equation:

$$A_t(u_i, v_i) - A_t(u_j, v_j) \geq K \tag{2}$$

Where Ai denotes the indexed DCT coefficient, (ui, vi), (uj, vj), are respectively the positions of the two selected coefficients with same quantization values and K is the gain factor resultant from this equation [1]. The redundancy introduced by the insertion of multiple watermarks encoded in the described coefficients, proved through experimental results that it introduces a higher robustness after different Stirmark attacks. An explanation for the increased robustness is that all or some of the embedded watermarks survives the applied attack each time.The embedding procedure is as follows where T denotes the DCT operator transform from the spatial to the frequency domain:

$$T^{DCT}(I_h) = I^{DCT} \tag{3}$$

In the embedding procedure every watermark is coded in one DCT coefficients instead of spreading it on two ore more selected coefficients. In this way, the distortions introduced to the watermark after each attack is minimized.

In fact if many coefficients are selected to hold each watermark, two risks can occur: The change of a high number of DCT coefficients by coding watermarks on them can alter the watermarked image even if a low embedding strength is applied and More the number of coefficients used to hold the watermarks is high more the probability to alter and change one or more of these coefficients is high. This leads to modify and change the embedded watermarks. In the embedding procedure, we chose to code each watermark in only one selected DCT coefficient instead of spreading it between different coefficients. Using this procedure, the selected coefficients in each block are equal to seven between sixty-four. That leads to decrease probability of watermark loss by the decrease of the used coefficients and increase of watermarks number. The size of the watermark characterizing the amount of embedded signal changes with the image size. After the transformation in the DCT domain, we select L_{max} coefficients chosen equal to the number of watermarks as detailed above, to obtain the selected DCT coefficients called I_{SL}^{DCT}. The used coefficients present identical quantization values. Let I_{W}^{DCT} be the watermarked image by L_{max} watermarks added to the selected DCT coefficients obtained as follows:

$$I_{W}^{DCT} : \{I_{W}^{DCT}(i,j) = I_{SL}^{DCT} + K\, W_L(i,j);\ 0 \leq i,j \leq P\} \tag{4}$$

and $SL \in \{1, 2, ..., L_{max}\}$. Where $+$ denotes the operation of watermarks adding to the selected coefficients of the 8×8 blocks represented by I_{SL}^{DCT} and W_L are the embedded watermarks. By applying an inverse DCT transform $T^{DCT^{-1}}$, as shown in equation (8), we obtain a spatial representation of a DCT multi-insertion watermarked image I_W^S.

$$I_W^S = T^{DCT^{-1}}(I_W^{DCT}) \tag{5}$$

2.3. Spatial watermark embedding:

2.3.1 Neural Network structure:

The neurons used, have the same nature as the linear neurons with a perception threshold. It applies a function to the inputs sum, this function is a smoothed version of the threshold function (all or nothing: 1 or 0). In this work, we use a "Sigmoid" function of the form:

$$f(y) = \frac{1 - exp(-ay)}{1 + exp(-ay)} \tag{6}$$

With "a" the sigmoid threshold.The characteristics of the network training steps are the update of the weights respectively to the inputs and the desired output. In order to get in the end of training a network able to simulate desired function or classify correlated or uncorrelated parameters with a great precision. In every step, one example is presented as input in order to calculate a real output from the first layer to the least, this step is called forward propagation. Then the error is established and injected in the network giving weights modification. In fact the training consists in decreasing the quadratic error of all the examples. The difficulty to carry out these steps in a multi layers network is the possibility to calculate the quadratic error derivative respecting to a given weight. Using a neuron with a derivable activation function allow to resolve this problem.

2.3.2. Neural network segmentation for zones classification and variable gain factors computing:

We choose to begin training the network on a test image (The cameraman). This image is chosen because it presents varied zones i.e. homogeneous and textured zones. This allows as verifying if the network is able to distinguish between the different image components and provide accurate classification. First, the neural network is trained with blocks randomly selected from three chosen zones of the image. The learned zones are the cameraman, the sky and the edges. For each zone three different patterns are introduced. In the test process, the network browses the entire image with a one-pixel overlap as presented in Figure 3. The network outputs three classes black if sky zone is detected (Homogeneous clear zones), gray for cameraman (homogeneous dark zone) and white for edges. Each browsed block belonging to the tested image is compared with the desired output. The corresponding outputs are used to substitute the original blocks and carry out the marked zones. We suppose the image I partitioned in a set of n associated blocks and B_i represents the compared image blocks as:$I = \{B_1, B_2, B_3, ..., B_n\}$. The segmentation result, is the new image I_s with the blocks B_i' holding the network decision. These blocks are able to hold only black, white or gray decision as $I_s = \{\acute{B}_1, \acute{B}_2, \acute{B}_3, ..., \acute{B}_n\}$. The different learned zones are classified and their respective edges are delimited. We tested three blocks with sizes equal to $(n \times n)$ pixels in the learning step, Where n belongs to $\{3, 5, 7\}$. In some regions, the 3×3 pixel size block can not cover the information variation existing in some image zones, whereas the 7×7 blocks introduce an undesirable redundancy in repeated equal values that leads to a rough segmentation in the test process. The optimal segmentation result shown in figure 5, is based on the use of block size 5×5.

The learned zones are the cameraman, the sky and the edges. For each zone three different patterns are introduced. In the test process, the network outputs black if sky zone is detected, gray for cameraman and white for edges. The best results correspond to a network composed by an input layers with

Figure 1: (a)Original image (Cameraman). (b)Segmentation obtained with a block of 5×5 pixels.

25 neurons, two hidden layer with 10 neurons and an output with one neuron. The original image (Cameraman) is automatically classified and marked as shown in figure 5 (b). Three different zones are sorted basing on their respective specificities where Z.1 represents the first zone marked in black that corresponds to a homogeneous zone (sky), Z.2 the second zone marked in Gray that corresponds to a dark homogeneous zone (the cameraman). The different edges are totally detected and marked with white. As we note in this figure, the zones containing details and repeated grey intensities variation (called third zone Z.3), are automatically kept without any marks. In fact it is difficult to insert watermarks in a zone containing different grey levels and details with a high gain factor with insuring simultaneously watermark invisibility and robustness. For every zone the appropriate gain factor called K, is automatically computed based on Weber's law [8] to keep the watermark imperceptible. A fine-tuning of the computed value is manually carried out, increasing it to reach the limits of the visual imperceptibility threshold as $\frac{\Delta I(i,j)}{|I(i,j)|} = CTE$. Where CTE denotes a constant chosen generally equal to 2(%) and $\Delta I(i,j)$ is the pixel difference between the watermarked and the original image. Once the gains are computed, this imperceptibility limit is also protected by the use of a security factor that reduces the possibility to visualize some details of the embedded watermarks even though the image is zoomed many times as:$K = K_c \times S_F$. Where K_c is the computed and adjusted gain factor, S_F is the used security factor. This factor is used equal to 0.9. From figure 5 (b), the neural network classification outputs three different gain factors used respectively with the watermarks embedded in the different showed zones. The values of these gains factors are respectively for zone 1, zone 2 and zone 3 as follows:$K = 0.02, 0.9\, and\, 0.15$.

2.3.3. Spatial embedding procedure:

As presented in the preceding section, the embedding procedure is applied in each of the found zones delimited by the neural network. The watermark shown in the section 1 is used to be inserted in seven locations of the resulting zones; In addition, the binary image resulting from grouping all the seven watermarks together and having the same size as the host image, is used as the eighth embedded watermark and a correlation with this image after the applied attacks is also considered. Because of the used binary watermarks, the embedding procedure derived from Weber's law and shown by equations (13-16) is variable from one pixel to another one in order to preserve the homogeny of the watermark spread over the different zones. This embedding procedure can be justified by the fact that HVS does not perceive equal changes in images equally, but visual sensitivity is nearly constant with respect to relative changes in an image. If is considered as a just noticeable difference, Weber's law is written as follows:

$$\frac{I_W(i,j) - I(i,j)}{|I(i,j)|} = CTE \tag{7}$$

If we consider that CTE is the watermark multiplied by the gain factor, it follows that:

$$\frac{I_W(i,j) - I(i,j)}{|I(i,j)|} = KW \tag{8}$$

Then by developing this equality the watermarking equation becomes:

$$I_W(i,j) = I(i,j)[1 + KW] \tag{9}$$

The general form of the embedding procedure in the proposed method takes into consideration the fact that the image is previously watermarked in the DCT domain with a set of watermarks as introduced by the following equation:

$$I^s_{WW} : \{I^s_{WWL}(i,j) = I^s_{WLn}(i,j)[1 + KW_{Ln}(i,j)]\} \tag{10}$$

Where L denotes the watermark index, L_max the maximum number of watermarks, N_s the total number of the segmented zones, n varies with the indexed zone as: $L \in \{1, 2, ..., L_max\}$
$and\, n \in \{1, 2, ..., N_s\}$.In this equation,$I^s_{WW}$ denotes the double watermarked image in the spatial and frequency domain.I^s_{WWL} is the watermarked image by L watermarks in the two domains,I^s_{WLn} represents the previously watermarked image in the frequency domain going to be watermarked the second time by the watermark number L in the n^th spatial classified zone of the spatial domain.W_{Ln} represents the watermark number L going to be embedded in

the $n^t h$ classified zone of the spatial representation and K is the variable gain factor determined by the segmentation process. The total embedded watermarks in the spatial and frequency domain are equal to fifteen, seven in the frequency domain and eight in the spatial domain;

III. ROBUSTNESS OF THE PROPOSED TECHNIQUE AGAINST AT TACKS

After concluding the watermarking process, the robustness of the proposed method is tested by applying different synchronous and asynchronous STIRMARK attacks on the watermarked image. Similarity between the extracted and the original watermark (W' and W) is determined in order to be sure that the inserted watermark is not affected by the different distortions applied on the image. The measure that is mainly used for similarities comparison and used in this work, is the normalized correlation.

3.1. Experimental results:

Different correlation values are computed between the recovered watermarks and the embedded ones in order to determine if the watermarks resist to these attacks. After every attack, fifteen correlations are computed corresponding to the fifteen embedded watermarks as shown in Table 2. While all the embedded watermarks are identical, in each set of correlations the higher one corresponding to the most resistant watermark to this specific attack is considered. The similarities rates and the used attacks are detailed in Table 3. To add more consistency to our results judgment, a second tool for computing visual image distortions is used. In tables 4 and 5, the peak signal to noise ration (PSNR)between the original and the attacked images is computed and its variation is illustrated against some attacks change. This distortion gauge is given by the following equations based on the mean square error of the image matrices:

$$PSNR = 10 \lg \frac{255 \times\ 255}{\frac{1}{N}\sum_{i-1}^{N} (I_i\ - \ddot{I}_{Wi})^2} \tag{11}$$

Where I and $\ddot{I}_{Wi})^2$ are the original and the attacked watermarked image. The PSNR computed between the original image and the watermarked image in both spatial and frequency domain is equal to 39.135 dB. Based on a studied selection of the embedding DCT coefficients and a good choice of the gain factor through a neural network classification of the embedding zone, this algorithm showed a high resistance to different attacks such as: JPEG compression, convolution filtering, rotations, rescaling, removing lines, rotation-rescaling and affine attacks [21].

JPEG 60 COMPRESSION								
Corr	Watermark 1	Watermark 2	Watermark 3	Watermark 4	Watermark 5	Watermark 6	Watermark 7	Watermark 8
Spatial	0.9039	0.9777	0.8643	0.9212	0.8788	0.9999	0.8659	0.7840
Freq-DCT	0.9869	0.9964	0.9783	0.9795	1	1	0.9601	

Table 1: Fifteen computed correlations in the spatial and DCT domains after a JPEG 60 compression attack.

ATTACKS	**CORRELATIONS**
Convolution Filtering 1	0.9527
Convolution Filtering 2	0.9066
Rotation −1	0.9235
Rotation 2	0.9148
Rotation 45	0.9183
Rotation 90	0.9111
Rotation-Scale 2	0.9192
Rescale 50	0.9302
Rescale 150	0.9207
Remove lines 20	0.9074
Remove lines 80	0.9089
Affine Filtering 3	0.9167
Affine Filtering 5	0.9189
JPEG Compression 20	0.9989
JPEG Compression 40	1
JPEG Compression 80	1
JPEG Compression 90	1

Table 2: The best correlation values corresponding to the described attacks.

High correlations are obtained using this method, which proves that the embedded watermarks were not damaged by the applied attacks. The redundancy used in the proposed embedding algorithm that consists in inserting multiples identical watermarks allow us to preserve at least one or more intact watermarks even if the others are damaged. This solution keep our correlation value the highest possible.

3.2. Watermarks detection and performances:

Respectively after each applied attack, the recovered watermark is compared with a set of one thousand random watermarks containing the original one. We proved by this set of experiments that between a thousand of different

JPEG Quality Factor	20	40	60	80	90
PSNR (dB)	28.108	28.613	28.922	29.221	29.406

Table 3: PSNR variation after different JPEG quality factor attacks.

presumed watermarks, the higher correlations corresponds to that computed between the original and the recovered watermark and there are no other similarities with other watermarks corresponding to a wrong detection.Using this method, high level of similarities is detected between the embedded watermark and the recovered one after most of the applied attacks. When compared with [2, 7] this method proved its efficiency for the high amount of embedded data and a better robustness against different geometrical attacks.

IV. CONCLUSION

In this paper, we presented a new approach, based on multi domain watermarking with multiple identical watermarks embedded in the spatial and frequency domains of the image representation. The number of embedded watermarks reached fifteen taking into consideration the number of classified zones in the spatial domain and the number of selected coefficients in the frequency domain. In the DCT frequency domain, a strategy to choose the DCT coefficients is developed. In this strategy, the watermarks are embedded in order to minimize the image distortion and obtain the maximum robustness of the different inserted watermarks. Whereas in the spatial domain, a neural network is used to learn blocks extracted from the image and outputs a classified image in different zones basing on these zones characteristics variation. In theses zones, an automatic computing of the gain factor used to embed the watermark based on Weber's law is considered. The simulation results proved that the proposed technique is robust against different synchronous and asynchronous attacks such as JPEG compression, different filtering and geometrical transformations. In the watermark detection process, we proved that all the embedded watermarks, have survived to a large set of the applied attacks. In addition, the redundancy caused by the multiple insertions has not altered the image quality however it increases the robustness of the proposed algorithm. High similarities after the attacked watermarked image are found in all the applied attacks kinds. The proposed method is also compared with different current well-known algorithms. The simulated evaluation proved that this method is much better than many other techniques in use.

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