Research on Improved Digital Image Encryption Watermarking Algorithm

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Abstract

The paper proposed an image digital watermark algorithm which is applied in printing monitoring system. It segments images to be printed into blocks with equal sizes through intensive embedding. It also carries out three-level discrete wavelet transformation. According to the self-adapting coefficient after the transformation at various levels, it adjusts the number of high-frequency sub-band sign coefficients to realize the embedding of watermark information; through uneven weighing, it extracts the watermark, which does not require source image. So long as the scanning resolution is above 75dpi, correct extraction could be done. According to the experiment, the algorithm could effectively defend the geometrical attacks and have robustness of scanning and could protect the copyright of documents to be printed and distinguish its source.

Keywords: Digital Image, Watermarking, Three-Level Discrete

1. Introduction

Extensive use of the print output devices leads to more and more pirate printed products. As the forgery technology becomes increasingly sophisticated, it also makes a number of important or confidential information leaked in the form of paper documents. The digital watermarking technology provides a method to protect the copyright and content security of print files. Watermark information can be computer ID number, printing time, the number of prints and copyright identification information [1-2]. The digital watermark should have two basic requirements of robustness and imperceptibility. The robustness refers to that watermark image after printing, copying, scanning and geometric transformations could still correctly extract the watermark; imperceptibility refers to watermark embedding will not bring significant changes to the print file, and thus it will not affect the its value. Watermark robustness and imperceptibility are mutually conflicting. The goal of the study of digital watermarking algorithm is to ensure that the watermark should not be perceived and the embedded digital watermark shows the best robustness [3]. According to the characteristics of digital image wavelet transform, it realizes the watermark algorithm in the wavelet domain. The experimental results show that the watermark when the premise of imperceptibility is satisfied, the algorithm is immune to the digital image printing, copying, scanning and general geometric transformation, noise limited impact, and has good robustness.

2. Wavelet Domain Image Watermark Embedding and Extraction

Wavelet analysis is a time-frequency domain localization method. It has many excellent characteristics to the apply wavelet transformation in the digital image [4], (1) wavelet transform can better reflect the characteristics of the image. The characteristics correspond to the relatively bigger details sub-band wavelet coefficient value of various levels; (2) provide multi-resolution representation for the image. It can directly process on the image level, image, provide hierarchical detection way to reduce the computational overhead for the image watermark; (3) wavelet transformation is flexible. There are many forms of wavelet transformation, which makes it able to adapt to certain types of images or a given special type of application.

The basic idea of the wavelet transform is image multi-resolution decomposition. It decomposed the image into different time frames and different frequency sub-image, which are more in line with the human visual mechanism. Generally speaking, the human visual sense is sensitive to subtle changes in smoothing part of the image and it is less sensitive to changes in image edge or texture [5]. After the image is decomposed into sub-graph by wavelet, the image information obtained good classification, and image edge or texture information mainly concentrate on the medium-and-high-frequency detailed
sub-graph larger wavelet coefficients, and, however, the image smoothing section mainly center on the low frequency wavelet coefficients. The present algorithm takes modifying the medium-and-high frequency wavelet coefficients to embed watermark.

Wavelet transformation in different scales decomposes the image layer by layer (layer k) into three high-frequency detail sub-bands: horizontal $c_{Hk}$, vertical $c_{Vk}$, the corner $c_{Dk}$ and a low-frequency approximation sub-band $c_{Ak}$. Approximation sub-band $c_{Ak}$ can follow this way to continue to be decomposed into $c_{Hk+1}$, $c_{Vk+1}$, $c_{Dk+1}$ and $c_{Ak+1}$. Among them, the low frequency band is determined by the largest scales of decomposition levels of wavelet transformation, best approximation of the original image under the minimum resolution. Its statistical feature and the original image are similar. In addition, most energy of the image is concentrated on this; series of high frequency band are the details of the image in different scales and resolutions. The lower the resolution, and the higher the proportion of useful information there would be. That is to say, after the wavelet it decomposes an image into several levels. As for the images at the same level, low frequency sub-image $c_{Ak}$ is the most important, followed by $c_{Hk}$ with $c_{Vk}$. High frequency sub image $c_{Dk}$ is relatively the least important. A for different levels, higher level means more importance and vice versa [6]. Therefore, the sequence of wavelet image sub-band frequency according to its importance is $c_{Ak}$, $c_{Hk}$, $c_{Vk}$, $c_{Dk}$, $c_{Hk-1}$, $c_{Vk-1}$, $c_{Dk-1}$, ..., $c_{H1}$, $c_{V1}$, $c_{D1}$, the various sub-band frequency value corresponded by wavelet image sub-band after transformation should be in line with corresponding wavelet coefficients. Coefficient distribution of different resolutions and different high-frequency sub-band are very similar, close to the Gamma distribution or a Laplace distribution. Each of the high-frequency sub-band coefficients are distributed largely in the zero-value, neighboring to the center point of probability density and the maximum values are zero. Effective treatment are fully used by the studies on the in-band and inter-band correlation as well as the wavelet coefficients near the zero value, with which one could realize the different embedding intensity and uneven weighing extraction of watermark at different sub-bands.

3. Algorithm Design

Geometric distortion and print scanning process will lead to larger changes of carrier information, the watermark extraction failure caused by destruction of the watermark information in the carrier, which requires the algorithm have strong robustness and also have a sufficient amount of embedding. As the geometric transformation and the print scan have limited impact on image DWT detail component [7], the watermark is embedded in the high frequency component of the DWT. Repeating embedding method is applied to enhance embedded effects and extraction correct rate.

3.1 Embedding Amount

Segment the image. In order to enhance the robustness of the algorithm, embed same watermark information into two-and-three high-frequency sub-band after the wavelet transformation of each image repeatedly. Algorithm embedding capacity and image block number are proportional. The smaller the image block number is, the more the number of sub-blocks, the more the amount of watermark embedding, but it will reduce robustness. Conversely, it will increase robustness, but the embedding amount is significantly reduced. While one ensures premise of robustness, the image block should be kept as small as possible in order to improve the amount of embedded.

3.2 Embedding of the Watermark

(1) Generate a watermark. Take out of the ASCII code of the watermark information and arrange them as $\{0, 1\}$ successively to obtain the watermarking sequence $W$.

(2) Partition the image in standardization, and carry out three level wavelet transform towards each image to obtain the six high-frequency sub-bands, namely, $c_{H3}$, $c_{V3}$, $c_{D3}$ and $c_{H2}$, $c_{V2}$, $c_{D2}$.

(3) Determine the adaptive coefficient Beita, which is achieved according to the statistical characteristics of the coefficients in the high-frequency components at the same level after the decomposition of the wavelet. After a certain level of wavelet is decomposed, we can get $c_{H}$, $c_{V}$, $c_{D}$ to form Matrix $C$, namely, $C = \{c_{H} \cup c_{V} \cup c_{D}\}$ . $N$ refers to the number of the coefficient in matrix $C$. 


suppose the threshold is \( T = \sqrt{\frac{N \times B_k}{N}} \), among which \( B_k \) is the central moment of \( k \) order in matrix \( C \), and find the number of coefficient \( X_i \), satisfying the need of \( |X_i| > T \) in matrix \( C \). The adaptive coefficient of the high-frequency component of the wavelet at this level is \( \delta = B_{\text{max}} \times \frac{N}{3} \). The embedding strength of the high-frequency component matrix of the wavelet decomposition at the same level is the same, that is, \( d = \delta = B_{\text{max}} \times \frac{N}{3} \). The embedding strength of the high-frequency sub-bands at the second and third level can be expressed by \( d_2 \) and \( d_3 \) respectively.

(4) Count the positive and negative numbers of the coefficients of \( c_{H3}, c_{V3}, c_{D3} \) \( \| c_{H2}, c_{V2}, c_{D2} \), and take \( c_{H3} \) as an example. Supposing \( z_{\text{eng}} c_{H3} \) and \( f_{\text{u}} c_{H3} \) refer to the number of positive and negative coefficients respectively in \( c_{H3} \), and \( d_3 \) means the embedding strength of the watermark, then the specific algorithm of the embedding watermark is as follows:

(a) When it comes as \( W_i = 0 \):
   If it comes as \( z_{\text{eng}} c_{H3} - f_{\text{u}} c_{H3} < d_3 \), then alter the negative number with the minimum absolute value to a positive number without changing the absolute value until \( z_{\text{eng}} c_{H3} - f_{\text{u}} c_{H3} \geq d_3 \).
   If it comes as \( z_{\text{eng}} c_{H3} - f_{\text{u}} c_{H3} \geq d_3 \), we need to try our best not to alter the coefficient on the premise of guaranteeing the robustness of the algorithm. Therefore, \( c_{H3} \) is not dealt with at this moment.

(b) When it comes as \( W_i = 1 \):
   If the case is \( f_{\text{u}} c_{H3} - z_{\text{eng}} c_{H3} < d_3 \), then alter the positive number with the minimum absolute value to a negative number without changing the absolute value until \( f_{\text{u}} c_{H3} - z_{\text{eng}} c_{H3} \geq d_3 \).
   If the case is \( f_{\text{u}} c_{H3} - z_{\text{eng}} c_{H3} \geq d_3 \), \( c_{H3} \) cannot be dealt with similarly.

The other five detailed sub-graphs of \( c_{V3}, c_{D3}, c_{H2}, c_{V2}, c_{D2} \) also change accordingly. Since the bigger value of the precise component in the wavelet transform is much closer to the edge details, the great alteration of the coefficient will give rise to distortion of the image. In order to ensure the invisibility of the watermark, we should alter part of the minimum coefficients of the absolute value.

Given the robustness of the watermarking algorithm, we embed same watermarking information in the six detailed sub-graph.

(5) Obtain the watermarked image block through the inverse wavelet transform of the adding watermark information data

### 3.3 Extraction of the watermark

The extraction of the digital watermark is the inverse process of embedding. Scan the watermarking image to be detected, partition the scanned image after pretreatment according to the method of embedding, and carry out three-level DWT transform to each image and count the numbers of the positive and negative coefficients in the six sub-graphs at the second and third levels. If the number of the positive coefficient is bigger than that of the negative coefficient, then we extract the information as 0, otherwise 1.

As for the same watermark information bit, the six bits of \( W_{\text{ch}3}(i), W_{\text{cv}3}(i), W_{\text{cd}3}(i), W_{\text{ch}2}(i), W_{\text{cv}2}(i) \) and \( W_{\text{cd}2}(i) \) extracted from the six high-frequency sub-bands of \( c_{H3}, c_{V3}, c_{D3}, c_{H2}, c_{V2}, c_{D2} \) may discord. Due to the different importance of \( c_{H3}, c_{V3}, c_{D3}, c_{H2}, c_{V2}, c_{D2} \), we take the measure of uneven weighting to extract. Bestow the extracted six bits with different weighting values, \( a_1, a_2, a_3, a_4, a_5, a_6 \), and make them meet the need of:

\[
\begin{align*}
|a_1 | & + |a_2 | + |a_3 | + |a_4 | + |a_5 | + |a_6 | = 1 \\
|a_1 > | & a_2 > |a_3 > |a_4 > |a_5 > |a_6 |
\end{align*}
\]

Make it as

\[
P = a_1 \times W_{\text{ch}3}(i) + a_2 \times W_{\text{cv}3}(i) + a_3 \times W_{\text{cd}3}(i) + a_4 \times W_{\text{ch}2}(i) + a_5 \times W_{\text{cv}2}(i) + a_6 \times W_{\text{cd}2}(i)
\]

When setting the weighting value, we should exclude the case that \( P \) equals 0.5, and determine the final watermarking information of \( \text{Water}(i) \) according to \( P \)'s value.

- If \( P > 0.5 \), then \( \text{Water}(i) = 1 \).
- If \( P < 0.5 \), then \( \text{Water}(i) = 0 \).

Figure 1 is the block diagram of the watermark detection algorithm.
4. Experimental Result and Analysis

The purpose of this experiment is to analyze the imperceptibility and robustness of the algorithm, in order to verify the effectiveness of the algorithm proposed in this paper. In robustness analysis, before print copy scan experiment, it establishes some attack model and adds watermark image noise, cropping, scaling and other processing to analyze the the anti-aggressiveness of the algorithm, and finally it carries out print copy scan experiment.

4.1 Experiment Scheme

(1) Program to realize embedding, algorithm extraction of the watermark. According to the robustness of the algorithm, one could divide the carrier images into image blocks sized 64*64bit.

(2) Select experimental platform and material. In the experiment, algorithm realizes on MATLAB7.1. The watermark carrier image is 256*256bit standard lena image whose information refers to 16 bit 0,1random sequence. The wavelet transformation adopts haar wavelet.

(3) Embed the water mark.

(4) Conduct noise attack, geometrical conversion, printing, copying and scanning on the watermark images. Here, pre-process the scanned images before extracting the watermark to verify the result.

(5) Evaluation of the effectiveness of the algorithm\(^8\)\(^9\). It includes the peak SNR, calculation of generalized relevant coefficient, noise attacks, geometrical conversions and experimental designing, printing, copying, scanning and others. Adopt the peak SNR to objectively evaluate the quality of the watermarked image. The SNR is:

\[
PSNR = 10 \times \log \left( \frac{m \times n \times \max_{(m,n)} f^2(m,n)}{\sum_{(m,n)} (f^*(m,n) - f(m,n))^2} \right)
\]

Here, the peak SNR unit is dB, \(f\) refers to the source carrier image; \(f^*\) refers to the watermarked image. Use generalized relevant coefficients to objectively evaluate the similarity between the extracted watermark and source watermark. The generalized relevant coefficient is:

\[
NC = \frac{\sum_{i \in \Omega(i)} W(i) \times W^*(i)}{\sum_{i \in \Omega} W(i)^2}
\]

Here, \(W\) refers to the source watermark; \(W^*\) refers to the extracted watermark sequence.

4.2 Experimental result

As shown by figure 2, the peak SNR of the source carrier image and the watermarked image stands at 32.4355dB.
It carried out noise attacks, geometrical conversions, printing, copying, scanning and others on the watermarked image.
As is shown in Figure 3, (a) - (d) refers to the effect after the watermarked image underwent a variety of attacks in MATLAB; (e), (f), respectively refer to the watermark image scanning and printing effect, in which the scanning resolution is of 75dpi and the copy stands at one time. Table 1 is shows the extraction of a watermark after various experiments. From figure 3, adding noise, cropping, scaling, has brought up obvious changes on lena image containing the watermark. Under the strength of the various attacks, the watermark information could still be entirely correctly extracted. The parameters of various attacks are the threshold of the algorithm. If one increases attack power, the extraction of the watermark information correct rate will decline. The algorithm print scan has good robustness, and is not sensitive to the scanning resolution. Despite scanning resolution is of 75dpi, one could correctly extract watermark. The paper also experimented scanning images with resolution of 300dpi, 600dpi and 1200dpi. The results show that the high-resolution scan will only lead to increased data processing capacity and does not enhance the efficiency of detection. The resolution of scanner used in the daily life is above 75dpi. The algorithm has the robustness on resolution of above 75dpi. It has less demanding on the scanning resolution, so it improves the scope of application of the algorithm. The correct rate of extracting the watermark information from the image after one print and scan declined, and the extracted 16-bit binary watermark sequence has an error occurred, with the correct rate of 93.75% and the correlation coefficient is 0.8750 with the original watermark sequence.

<table>
<thead>
<tr>
<th>Name</th>
<th>gaussian noise</th>
<th>impulse noise</th>
<th>cutting 30%</th>
<th>contracting</th>
<th>print-scan</th>
<th>print-copy-scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CER</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.8750</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>93.75%</td>
</tr>
</tbody>
</table>

The experimental result is mainly analyzed from two perspectives namely, the imperceptibility. Invisibility of the watermark includes objective imperceptibility and subjective imperceptibility. Objective imperceptibility can be reflected by indicators PSNR. Larger PSNR values indicate the better imperceptibility. Generally, the PSNR achieving 25 or more could reach the requirement of objective imperceptibility [10]. In experiment, PSNR is 32.4355, and the requirement of imperceptibility is met. Subjectively, it mainly depends on the senses of the person's own feeling. Through the image of the experiment, a relatively satisfactory result in terms of visual sense has been basically achieved. In summary, the algorithm meets the requirements of imperceptibility.

In anti-print copy, scan, and digital watermarking algorithm, due to the image itself experienced print, copy, scan, as well as geometric transformation, noise attack that robustness is a need to focus on becomes a difficult point worth considering. Extract the watermark in the experiment by designing a variety of attacks, as well as by extracting binary watermark sequences and original watermark sequence similarity to characterize the anti-attack capability. It can be clearly seen through the experimental results, the algorithm show good robustness against various attacks: such as noise, shearing, scaling, printing, printing and scanning.
5. Conclusion

In this paper, a wavelet domain digital watermarking algorithm is proposed. The algorithm can achieve blind detection of the watermark. By segmenting the image into sub-blocks of 64 * 64bit, it allows the algorithm to have a certain amount of watermark embedding. In the embedding process, according to the image statistical characteristics it introduced the self-adapting coefficient to adjust embedding intensity. While minimizing changes in the original image, it makes the images embedded with watermark information show fine visual effects. The peak signal-to-noise ratio is more than 25dB. In the extraction process, the method uses the unevenly weighted rate to improve the accuracy of extracting a watermark. The algorithm can be effective against certain degree of noise attack, cropping, scaling, and print scan, and could correctly extract watermark given a resolution more than 75dpi. In addition, it has robustness on scanning after one printing or copying. Watermarked image after the scanning needs to be pretreated, including images of the tilt correction, cutting edges as well as adjustment of the size of the image scanned so as to adjust the size of the scanned image to the same as with the original image.

5. References