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A Novel Digital Watermarking Algorithm Based on Wavelet Lifting Scheme and Linear Regression

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Abstract

A novel digital watermarking algorithm is proposed in this paper, which is based on Linear Regression Constrains and Wavelet Lifting Scheme. Firstly we define a fixed matrix Q and use matrix Q MOD (Modulus after Division) the low-frequency data. The data is extracted from the 1-level wavelet decomposition of each sub-image. According to the remainder matrix, we can embed and extract watermark. The simulation results show that watermarked image can obtain a large value of PSNR and demonstrate that the algorithm has strong robustness to resist noise and clipping attacks, it also can greatly reduce carrier image distortion.

Keywords:digital watermark;linear regression ;lifting wavelet transform ; information hiding

1. Introduction

Digital watermarking is proposed recently as a copyright protection technology. According to the characteristic of the redundant data and randomness of digital works, it embeds the copyright information into the digital works, helping to protect the copyright of digital works. Digital watermarking can identify and verify the information of author, owner, publisher or authorized consumer which is extracted from the digital images, videos and audio recordings, it also can trace the illegal distribution of digital works. At present, it is a more effective measure to protect digital works.

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Watermarking technology is divided into spatial domain and transform domain [1] currently. Space domain algorithm [2-4] is very simple. By using this algorithm, large amount of information can be hided and the speed of watermark information embedding and extraction is very fast. LSB (Least Significant Bit) is a classical algorithm in the Space domain, but the robustness of the algorithm and the ability of resist attack are very poor. However, transform domain [5-6] has a strong robustness to against the watermark attack, but the algorithm is very complex and the amount of calculation is very large. In this article, we introduce a new digital watermarking algorithm, which is based on linear regression and wavelet lifting Scheme.

2. Knowledge Description

2.1. Linear regression model

We often find that there is a certain relationship between the variables *x* and *y*, which is called correlation in statistics. As a kind of statistics conception, regression is used to study the correlation. Regression model is always established by the Least squares and we can use it to calculate the min value of the error square sum. Defining the formula as follow:

$$E_{\min}=\sum_{i=1}^{n}\left[y^{S}-y^{G}\right]^{2} \tag{1}$$

In this formula, y^s is experimental value and y^G is obtained from the model which is established by the special variable x .This article uses linear model and it is defined as follow:

$$y=ax+b \tag{2}$$

By the formula (2), we can get the next two Least squares linear equations.

$$\sum y_i = a\sum x_i + nb \tag{3}$$

$$\sum x_i y_i = a\sum x_i^2 + b\sum x_i \tag{4}$$

The values of *a* and *b* can be calculated by formula (3) and (4).

$$a=\frac{n\sum x_i y_i-\left(\sum x_i\right)\left(\sum y_i\right)}{n\sum x_i^2-\left(\sum x_i\right)^2} \tag{5}$$

$$b=\frac{\left(\sum y_i\right)\left(\sum x_i^2\right)-\left(\sum x_i\right)\left(\sum x_i y_i\right)}{n\sum x_i^2-\left(\sum x_i\right)^2} \tag{6}$$

Because $\bar{x}=\frac{\sum x_i}{n}$ and $\bar{y}=\frac{\sum y_i}{n}$, when we put $\bar{x}$ and $\bar{y}$ into the formula (5) and a new simple formula (7) can be achieved.

$$a=\frac{\sum\left(x_i-\bar{x}\right)\left(y_i-\bar{y}\right)}{\sum\left(x_i-\bar{x}\right)^2} \tag{7}$$

At last, we make the value of slope a as our constrain condition.

2.2. Arnold scrambling technology

We use two-dimensional Cat-Map algorithm to do the chaos scrambling for watermark image. Then the two-dimensional Cat-Map can be defined as follow:

$$\begin{bmatrix} x_{n+1} \\ y_{n+1} \end{bmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{bmatrix} x_n \\ y_n \end{bmatrix} = A\begin{bmatrix} x_n \\ y_n \end{bmatrix} \bmod F \tag{8}$$

In this formula, MOD function is to obtain the remainder and F is a column matrix, $a_{11}, a_{12}, a_{21}, a_{22}$ are the non-negative integers. According to $|3A| = a_{11}a_{22} - a_{21}a_{12} = 1$, we can determine Cat-Map by its three parameters. When $a_{11} = a_{12} = a_{21} = 1$ and $a_{22} = 2$, it is called Arnold Scrambling.

3. Watermarking Embedding and Extraction

Firstly, let the original image be denoted as $\mathrm{I}=\{\mathrm{h}(i,j), 1<i<M, 1<j<N\}$ and the binary watermarking be denoted as $W = \{w(i,j), 1<i<P, 1<j<R\}$. Then we define a fixed matrix Q, by which we can get a remainder matrix.

For example, we define a matrix Q as $\begin{bmatrix} 5 & 5 \\ 5 & 5 \end{bmatrix}$ and assume the sub-block of low-frequency data is $\begin{bmatrix} 189 & 161 \\ 158 & 148 \end{bmatrix}$. If we directly calculate the mean value of sub-block and use the mean value matrix to cover the original data, the new matrix of sub-block is $\begin{bmatrix} 164 & 164 \\ 164 & 164 \end{bmatrix}$ (when take the mean value, it usually uses the method of Rounded Down) recorded as $m1$. However, if we use the matrix Q MOD the sub-block data, then the sub-block matrix can be divided into the remainder matrix $\begin{bmatrix} 4 & 1 \\ 3 & 3 \end{bmatrix}$ and the divisible matrix $\begin{bmatrix} 185 & 160 \\ 155 & 145 \end{bmatrix}$. Because the mean value of the remainder matrix is $\begin{bmatrix} 2 & 2 \\ 2 & 2 \end{bmatrix}$, then let the mean value matrix plus the divisible matrix and get a new matrix $\begin{bmatrix} 187 & 162 \\ 157 & 147 \end{bmatrix}$ recorded as $m2$ .Comparing $m1$ and $m2$ with original sub-block data, the matrix $m2$ is more similar to original sub-block. The data that processed with the second method approximates original data more, thus we can greatly reduce the distortion of carrier image by using this method.

The process of watermarking embedding and extraction can be described as follows:

Step 1: Scrambling the original watermarking by Arnold image scrambling algorithm, which not only can improve the security of watermarking but also can improve the algorithm robustness to against clipping attacks. Then the shuffled watermarking is arrayed into a vector in column-wise order, which is denoted as:

$$w^* = \{w_i^* \mid i = 1,2,3.....,P\times R; w_i^* \in \{0,1\}\}$$

Then define a fixed 4×4 matrix Q:

$$Q = \begin{bmatrix} 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \end{bmatrix}$$

Step 2: Dividing the original image into 8×8 non-overlapping sub-image, then for each sub-image conducting 1-level integer LWT operation, extracting low-frequency sub-band data as a new 4×4 Sub-block B_i. From top to bottom and from left to right, the Sub-blocks order is denoted as:

$$B_i, i = 1,2,3....\lceil M/8 \rceil \times \lceil N/8 \rceil$$

$\lceil\ \rceil$ is the function of Rounded Down.

Step 3: Using matrix Q to MOD each sub-block B_i, the remainder matrix is called C_i and save the divisible matrix as D_i .The coordinates for fitting straight line is constituted by the m^{th} row , n^{th} column pixel and $(m+1)^{th}$ row , n^{th} column pixel ,which are belong to each sub-block C_i. The slope of the straight line recorded as a .

Step 4: Defining a range for the slope which is from 0.9 to 1.1.If the slope of the C_i contained in the range, then this sub-block will be selected to embed watermark. When the corresponding bit of watermarking is equal to 0, choosing four adjacent pixels in matrix C_i, calculating their mean and making their mean value to cover those selected pixels record as $C_i^{'}$. If the corresponding bit of watermarking is equal to 1, all the sub-block pixels will not be modified .Then record the sum of $C_i^{'}$ and D_i as new matrix $B_i^{'}$ and conduct inverse integer LWT.

Step 5: Loop step 2 to step 4 until all the sub-blocks be traversed, getting watermarked image $I^{'}$.

Watermarking extraction process is the same as embedding watermark process. According to the value of slope, we can judge watermarking information exists or not .If the watermarking information exists, then check corresponding sub-block $C_i^{'}$ whether it has four adjacent pixels that are the same value in the selected position or not, by which we can judge extracted watermarking information is 1 or 0.

4. Simulation Results

The standard image "*lena*" with $512 \times 512 \times 8$ bits is used to carry out the experiment and the binary watermarking image with $32 \times 32 \times 2$ bits is embedded in the carrier image and then generates the watermarked image, which is shown in the Figure 1. NC as normalized correlation coefficient is used to express the distortion of extracted watermark.

When the watermarked image is without under attack, the Peak-Signal-to-Noise Ratio (PSNR) between the carrier image and the watermarked image is 58.9. Comparing original watermark with A, the value of NC is 1. Comparing carrier image with Reference [7], the PSNR is 48.5 and the corresponding NC is 0.9981.

Figure 1.Watermarking, Carrier image and Watermarked image.

Do the clipping and the noise attack operation separately for the watermarked image, the degree of clipping are 25%, 55% and 70%. In the Figure 2, Figure 2(a), Figure 2(b), Figure 2(c) are the watermarking which are extracted from the corresponding clipping watermarked image. The results show that the watermarking can be extracted perfectly and the algorithm can resist the 70% clipping attack. For the watermarked image add salt & pepper noise, Figure 2(d) and Figure 2(e) are the corresponding extracted watermarking. The NC is 0.9867 under the situation of 0.02 salt & pepper noise attack. However, the algorithm of Reference [7] can't resist the noise attack.

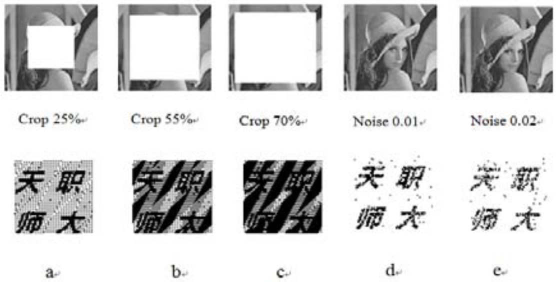

Figure 2. The experimental results for the clipping and noise attacks.

5. Conclusion

In this paper, a simple digital watermarking algorithm is proposed, which is based on IWT and Linear Regression Constraints. A novel method of obtain the remainder matrix is introduced to the algorithm, which assumes a fixed matrix Q firstly, then lets the matrix Q MOD the low-frequency data, at last we get a new remainder matrix. According to the remainder matrix, we can determine the watermarking embedding and extraction. Especially, it can greatly reduce the distortion of carrier image. The experimental results demonstrate that the robustness of invisible watermarking algorithm is very good and PSNR can be improved to 58. It not only can perfectly extract the watermarking but also has strong robustness against the clipping and the noise attacks. How to improve the robustness of algorithm to resist other watermarking attack is the further issue that we need to study.

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