Digital Watermarking Security in the Printing and Scanning Process of Image

Hai-sheng Chen
Department of Packaging and Printing, Zhongshan Torch Polytechnic, Zhongshan, China, 528136

Abstract

In this paper, a novel security method based on digital watermarking in printing and scanning is studied, and a watermarking algorithm based on discrete wavelet transform is proposed. First all, the principles and color space theory of color image watermarking is analyzed, and color distortion and geometric error caused by printing and scanning process are discussed. According to singular value decomposition and wavelet multi-resolution analysis, the digital watermarks were embedded into color image through embedding watermark into singular value of wavelet coefficients matrix. After embedding, the color image was printed with inkjet printer and scanned after the digital watermarks were embedded, then watermark extraction and Evaluation was performed. Experiment results show that the robustness and invisibility of this algorithm are strong, and that the digital watermarking proposed in this paper would be stand against general printing and scanning process. Compared with other anti-counterfeiting technology in security printing, the method in this paper has the advantages of low cost and simple implementation.

Introduction

With the development of the printing industry, the forgery of printing product is more and more serious, and traditional anti-counterfeiting technology of printing is very difficult to meet security printing. In this paper, digital watermarking is used into forgery prevention of ink-jet printing. At present, most research of digital watermarking is mainly for digital works in computer, and not for security printing. So, the topic of this research is application of digital watermarking on security ink-jet printing, in which watermark is embedded into original image and the watermark would be extracted from printing image after ink-jet printing to verify copyright of product. Taking into account the human visual system, the watermark was embedded into digital image using discrete wavelet transform and Singular value decomposition. After ink-jet printing, the printing image would be scanned into computer in which the watermark is extracted from printing image. Results of digital watermarking would be obtained from the comparison of the extracted watermark and original watermark.

Wavelet Transform

Wavelet transform is a new mathematical tool developed in the past 10 years, and is another important breakthrough following the Fourier analysis more than 100 years ago. Wavelet analysis is a new signal analysis theory, a new time-frequency analysis method, and has more advantages than other time-frequency analysis. The basic idea of wavelet transform is that image is decomposed into many sub-images which are in different time and different frequency severally by multi-resolution decomposition, and this transform is more in line with the human visual system. In general, the smoothing area in image is sensitive for human, but the edges or textures are less sensitive. The image information is categorized after wavelet transform, image edge information and texture information is mainly concentrated in the larger wavelet coefficients in the high-frequency sub-images, and the information of smoothing area is concentrated in the low-frequency wavelet coefficients. So, some kind of feature information can be embedded by modifying the wavelet coefficients.

Wavelet transform is divided into continuous wavelet transform and discrete wavelet transform. The wavelet transform of digital image is two-dimensional discrete wavelet transform and the algorithm is actually Multi-resolution decomposition proposed of Mallat tower by Mallat [1]. If the whole image $f(x,y)$ is seen as a discrete approximation of a resolution $2^0=1$, it can be decomposed into a $A_J f$ approximation of lower-resolution 2^{-J} and a number of successive approximation $D_j f$ of high-resolution $2^{-j}(0<j<J)$. Wavelet decomposition of Mallat tower is shown in Figure 1, where *Hr* is low-pass filter and *Gc* is high-pass filter. Decomposition diagram is shown in Figure 2, where *L* denotes low-frequency, *H* denotes high-frequency, and subscript 1 and 2 indicate the layer of wavelet decomposition. Comparing Figure 1 and Figure 2, $A_{j+1}f$ is correspond to *LL1*, $D^1_{j+1}f$ is correspond to *LH1*, $D^2_{j+1}f$ is correspond to HL1, and $D^3_{j+1}f$ is correspond to HH1.

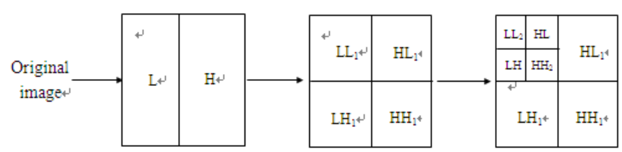

Figure 1: Wavelet decomposition of image

Singular Value Decomposition

According to linear algebra, a monochrome digital image can be regarded as a matrix *A*, and $A=\{a_{ij}\}_{m\times n}(m\ge n)$, where

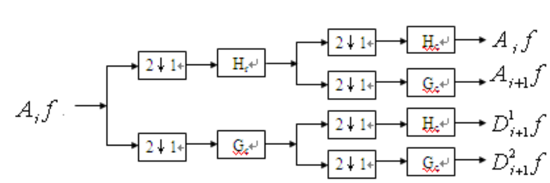

Figure 2: Wavelet decomposition of Mallat tower

rank(ATA)=rank(A)=r $(0<r\le n)$. If $\sigma_i(i=1,2,...,n)$ is supposed as the matrix eigenvalue of n order matrix *ATA*, and $\sigma_1\ge\sigma_2\ge...\ge\sigma_r>\sigma_{r+1}=...=\sigma_n=0$, $\lambda_i=\sqrt{\sigma_i}$ $(i=1,2,...,n)$ is regard as the Singular value of matrix A. Then there are an m-order orthogonal matrix U and an n-order orthogonal matrix V which are exit in Equation (1).

$$A = U\begin{pmatrix} D & 0 \\ 0 & 0 \end{pmatrix}V^T \quad (1)$$

T indicates the transpose of matrix. Equation (1) is called the singular value decomposition of image matrix A, and D is an r-order matrix, $D=diag\ (\lambda_1, \lambda_2, ..., \lambda_r)$, where *diag* is a diagonal matrix in which all non-diagonal elements are zero. $\lambda_i (i = 1, 2, ..., n)$ is the singular values of A. U is called the left singular matrix, and the corresponding orthogonal vectors Ui (i = 1,2, ..., m) are left-singular vectors. V is called the right singular matrix of A, and the corresponding orthogonal vectors Vi (i = 1,2, ..., n) are the right singular vectors. Decomposition steps include solving eigenvalue , seeking singular value λ_i , solving orthogonal eigenvectors γ_i^u in AA^T and γ_i^v in AA^T, unitizing eigenvectors, and arranging these eigenvectors in orthogonal vector group . The standard orthogonal U and V will be obtained by the above mentioned decomposition steps. The computing formula is shown in Reference [2].

If A is a digital image, A can be regarded as two-dimensional time-frequency information. Then, the formula of the singular value decomposition is as follows:

$$A = USV^T = U\begin{bmatrix} D & 0 \\ 0 & 0 \end{bmatrix}V^T = \sum_{i=1}^{r} A_i = \sum_{i=1}^{r} \sigma_i u_i v_i^T$$

Where $U * U^T = I$, $V * V^T = I$, u_i is the column vector of U, v_i is the column vector of V, and σ_i is the non-zero singular values of A . So, digital image A can be seen as a superposition of r sub-images which of rank are 1, and the singular value σ_i is weights. Application of singular value decomposition on image processing has many advantages. The stability of image singular value is very good, that is, singular value would not be changed more when minor disturbance are imposed on image. Image processing and image attack are similar as image disturbance, so embedding a watermark into the singular values would make strong robustness. In the meantime, Singular value is a symbol of image intrinsic characteristics and not image visual characteristics, so change of singular value will not cause large visual changes and watermark invisibility can be improved. In this paper, watermark was embedded into the singular value of digital image.

Digital Watermarking

Digital watermarking is divided into two process of embedding watermark and watermark extraction.

Embedding watermark

Embedding watermark includes the following steps: image Arnold scrambling, color space conversion, wavelet transform of luminance component, singular value decomposition, embedding watermark, constructing watermarking image.

Image scrambling is kind of image encryption in which image will be became chaotic through disturbing the location or color of image pixels, and it is often used in pre-processing and post-processing of digital watermarking. After image scrambling, the total number of pixels and histogram would be changed. Because scrambling the watermark can remove the spatial correlation of pixels, digital watermark can improve the robustness of anti-printing and anti-scanning. Image scrambling is not only achieved in spatial domain, but also in frequency domain. Arnold scrambling was used in this paper, which is a transform proposed in the study of Ergodic theory, and was known as cat mapping. The scrambling formula is (3) as follows:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix}(\mathrm{mod} \quad N) + \begin{pmatrix} 1 \\ 1 \end{pmatrix} \quad (3)$$

Where *(x, y)* is the pixel in original image, *(x', y')* is the pixel in scrambled image, and N is the number of image order which indicate image size. Scrambling frequency is seen as the key of embedding watermark.

Different equipment and color space would be used in computer, printer and scanner, so image color would be distorted in printing and scanning. For reducing color distortion, *RGB c*olor space was converted to *CIEL*a*b** color space which is a device independent color space. Conversion of color space contains two steps. The first is the conversion of *RGB* to *CIEXYZ* in accordance with the formula (4), and second is the conversion of CIEXYZ to *CIEL*a*b** in accordance with reference [5].

$$\begin{aligned} X &= 0.490R + 0.31G + 0.200B \\ Y &= 0.177R + 0.812G + 0.011B \\ Z &= 0.010G + 0.990B \end{aligned} \quad (4)$$

From above conversion, a matrix of *256×256* which indicates the brightness of original image would be achieved, and embedding watermark into this matrix would not cause image color change.

After conversion of color space, the color space of image is *CIE L*a*b**. The matrix *L** which are the luminance component of image will be decomposed by two-dimensional discrete wavelet of two layers, and the algorithm is Mallat decomposition mentioned above. Four matrix of 64×64 with different sub-band coefficient would be achieved. The four matrix is A_m, where m=1, 2, 3, 4, are the frequency band of *L2*, *LH2, HL2, HH2* (shown in Figure 2) respectively.

The next step after wavelet decomposition is singular value decomposition. Am would be decomposed according to formula (5) as follows:

$$A^m = U_m S^m V_m^T \quad (5)$$

Where S^m is singular value matrix of wavelet coefficient matrix with different frequency band, and the size is *64□64.* If σ_i^m (i=1,2,…,64) are the diagonal elements of S^m, σ_i^m are the singular values of A^m. U_m is the left Singular value vector, V_m is the right, and both of size is all *64□64*, where m=1, 2, 3, 4, are the frequency band of *L2, LH2, HL2, HH2* (shown in Figure 2) respectively.

In this paper, watermark is a gray image of *64□64*, and it s not suitable to be directly embedded. So, the singular value vector is selected as watermark, thus the amount of data is reduced, and it should be decomposed through the singular value decomposition according to formula (6).

$$W = U_w S_w V_w^T \quad (6)$$

Where S_w is the singular value matrix, and the size is *64□64.* If σ_{wi} (*i=1,2,...,64*) are the diagonal elements of S_w, σ_{wi} are the singular values of watermark. U_w is the left Singular value vector, V_w is the right, and both of size is all *64□64.*

Embedding watermark is actually that the singular value of watermark is embedded into the singular value of original image decomposed. The embedding formula is (7) shown as follows:

$$\sigma_i^{wm} = \sigma_i^m + \alpha_k \sigma_{wi} \tag{7}$$

Where σ_i^{wm} (*i=1,2,...,64 ; m=1,2,3,4*) is the singular value after embedding, α_k is factor of embedding intensity in different frequency band which can make robustness and invisibility balance. Among the four frequency bands, the singular value of *LL2* is the maximum, so the corresponding intensity factor α_1 should be larger. In this paper, $\alpha_1 = 0.2$. The intensity factors of the other three sub-band are selected as the same small value $\alpha_2 = 0.06$, because the impact of them on watermark is little.

The diagonal matrix of singular value S_{wm} would be achieved after embedding watermark, and corresponding matrix of wavelet coefficients would be obtained from formula (8).

$$A^{wm} = U_m S^{wm} V_m^T \tag{8}$$

Then, A^{w*} which indicate luminance component of image embedded watermark was calculated by two-dimensional inverse discrete wavelet transform of A_{wm}. A is corresponding to *L** in *CIEL*a*b** color space, and the color image *I** after embedding watermark would be get by inverse transform of color space.

Watermark Extraction

In this paper, watermark extraction must be in the condition that there is original image, and extraction is mainly six steps, and there are color space transform, discrete wavelet transform, singular value decomposition, extraction of the watermark singular value, reconstructing watermark image, and inverse Arnold scrambling. The first three steps and the sixth step are similar to embedding watermark, but the extraction of watermark singular value is followed as formula (9).

$$\sigma_{wi}^m = (\sigma_i^{wm} - \sigma_i^m) / \alpha_k \tag{9}$$

Where σ_{wi}^m is the singular value of watermark extracted from the frequency band of *m*. These singular value σ_{wi}^m are arranged into a diagonal matrix S_w^{*m}, and watermark W_k would be reconstructed following formula (10).

$$W_m = U_w S_w^{*m} V_w^T \tag{10}$$

The desired watermark would be achieved by inverse Arnold scrambling of reconstructing watermark.

Experiment and Results

In this paper, the original color image is lena provided by the international standard test library of digital watermarking, the size of which is *256×256*, as shown in Figure 3. The watermark is the gray badge image of South China University of Technology, the size of which is *64×64,* as shown in Figure 4. In-jet printer is EPSON stylus pro 7880C, and scanner is the Great Wall desktop scanner. The printing paper is glossy photo paper with the basis weight of 200g/m2. The image after embedding watermark was shown as Figure 5.

The watermark invisibility is evaluated through calculating the PSNR value between Figure 5 and Figure 3, and the lager the value is, the better the invisibility is. The PSNR of R component is 27.2648, the PSNR of G component is 29.5983, and the PSNR of B component is 29.6716. From above values, the watermark in this paper is invisible. The PSNR is calculated according to formula (11) shown as follows:

$$PSNR = 10\log_{10}\frac{255^2}{MSE}$$
$$MSE = \frac{1}{M \times N}\sum_i \sum_j (T_{ij}^* - T_{ij})^2 \tag{11}$$

Where T_{ij} or T_{ij}^* is the value of image pixel, and $\overline{T_{ij}}$ or $\overline{T_{ij}^*}$ is the corresponding mean value.

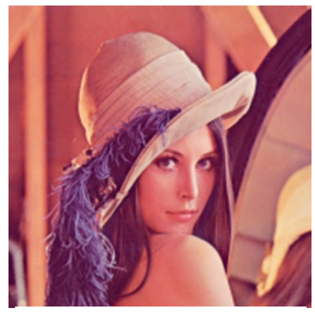

Figure 3: original image

Figure 4: watermark

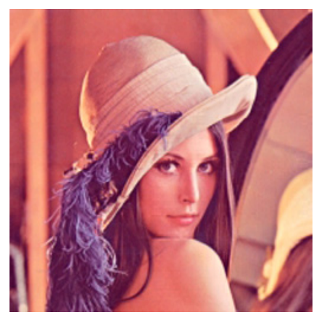

Figure 5: embedding watermark

After ink-jet printing, Figure 5 was scanned into computer with the scanning resolution of 300DPI, and scanning image would be achieved as shown in Figure 6. There is color distortion between Figure 5 and Figure 6 for color management was not used in printing and scanning. If the watermark can be extracted effectively without color management in printing, it shows that the digital watermarking algorithm is more advanced. Before watermark extraction, image preprocessing must be done in *PHOTOSHOP*. The watermark extracted is shown as Figure 7.

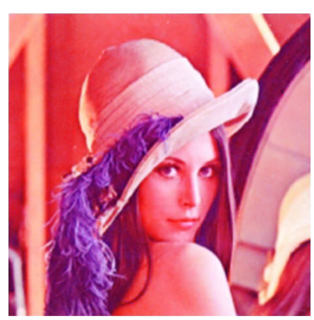

Figure 6: scanning image

Figure 7: watermark extracted

The value of r which is in interval of [0, 1], is used in evaluation of the robustness. The closer to 1 the r is, the stronger the robustness is. The calculating of r value is shown as in formula (12).

$$r = \left| \frac{\sum_i \sum_j (W_{ij}^* - \overline{W_{ij}^*})(W_{ij} - \overline{W_{ij}})}{\sqrt{\sum_i \sum_j (W_{ij}^* - \overline{W_{ij}^*})^2} \sqrt{\sum_i \sum_j (W_{ij} - \overline{W_{ij}})^2}} \right| \qquad (12)$$

Where w_{ij} or w_{ij}^* is the value of watermark image pixel, and $\overline{w_{ij}}$ or $\overline{w_{ij}^*}$ is the corresponding mean value. The value of r between watermark extracted and original watermark in this paper is *0.9193*, which is very closer to *1*. So the robustness is strong.

Conclusion

With the development of commodity economy, the counterfeiting of printing product is increasingly serious. Application of digital watermarking on security printing is studied in this paper. Regarding HVS and based discrete wavelet transform and singular value decomposition, the digital watermarks were embedded into color image. After ink-jet printing and scanning, the watermark can be extracted effectively. Experiment results show that digital watermark is invisible, the robustness is very strong, and it can resist to conventional printing and scanning. This research provides a good method of digital watermarking application on security printing.

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Author Biography

Chen Haisheng (1978-): Male, Master, an lecturer in Zhongshan Torch Polytechnic. His work focuses on image processing and printing technology etc.

Emai: hnchs@126.com