Journal of Southeast University (English Edition) Vol. 28, No. 4, pp. 386 - 391 Dec. 2012 ISSN 1003—7985

Contourlet watermarking algorithm based on Arnold scrambling and singular value decomposition

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Abstract: A new digital watermarking algorithm based on the contourlet transform is proposed to improve the robustness and anti-attack performances of digital watermarking. The algorithm uses the Arnold scrambling technique and the singular value decomposition (SVD) scheme. The Arnold scrambling technique is used to preprocess the watermark, and the SVD scheme is used to find the best suitable hiding points. After the contourlet transform of the carrier image, intermediate frequency sub-bands are decomposed to obtain the singularity values. Then the watermark bits scrambled in the Arnold rules are dispersedly embedded into the selected SVD points. Finally, the inverse contourlet transform is applied to obtain the carrier image with the watermark. In the extraction part, the watermark can be extracted by the semi-blind watermark extracting algorithm. Simulation results show that the proposed algorithm has better hiding and robustness performances than the traditional contourlet watermarking algorithm and the contourlet watermarking algorithm with SVD. Meanwhile, it has good robustness performances when the embedded watermark is attacked by Gaussian noise, salt-and-pepper noise, multiplicative noise, image scaling and image cutting attacks, etc. while security is ensured.

Key words: digital watermarking; contourlet transform; Arnold scrambling; singular value decomposition (SVD)

doi: 10.3969/j.issn.1003 - 7985.2012.04.003

With the development of the Internet, many people and companies want to realize copyright protection of their products presented in the Internet. Digital watermarking is a technology to embed copyright information into digital carriers (including image, audio and video) so as to protect the copyrights of digital products. It also can be used to verify the authenticity of the products, and traces the transmission and exposition of the products[1]. Nowadays, many researches focus on the transform domain digital watermarking technology, i.e., embedding watermarks into transform domain coefficients of digital carriers. The transform types used in digital watermarking include the discrete Fourier transform (DFT), the discrete cosine transform (DCT), the discrete wavelet transform (DWT) and the contourlet transform, etc.

The contourlet transform was first proposed by Do and Vetterli[2] to realize a new image representation method in 2002. It not only has the capabilities of multi-resolution presenting, but also localizes time and frequency characteristics provided by the wavelet transform. However, the contourlet transform can provide the anisotropic function that the wavelet transform does not support. This function ensures a higher efficiency in the singular geometric characteristic capturing which leads to more efficiency in image representation than the wavelet transform. Moreover, much literature[3-4] has described the use of the contourlet transform in digital watermarking and has got better performance than those algorithms using the DCT or the wavelet transform. Based on the contourlet transform, Akhaee et al.[5] proposed an algorithm which uses a general Gaussian distribution with zero mean values to estimate the coefficients of the contourlet transform, and then embeds the watermark into the right points in the carrier image. The performance against noise attacks of the contourlet scheme in Ref. [5] is good, and the features of the contourlet transform are analyzed in Ref. [6]. The singular value decomposition (SVD) scheme was first proposed in Ref. [7] to embed the watermark into the right points in the carrier image. Based on the SVD scheme, the hiding capacity is enhanced and the robustness against attacks is improved. However, there are still many research works needed to be done to improve the performance of the contourlet transform in digital watermarking.

In this paper, a new contourlet domain digital watermarking algorithm based on the Arnold scrambling technique[8] and the SVD is proposed to improve security and robustness performances. After the carrier image is transformed in the contourlet domain, we obtain the intermediate frequency singularity values from the SVD processing of the transformed data. Then the watermark bits scrambled in Arnold rules are dispersedly embedded into the selected SVD points so as to improve the robustness of the algorithm against attacks. Simulation results show that the proposed algorithm gains better hiding and robust-

Received 2012-07-18.

Biography: Chen Liquan (1976—), male, doctor, associate professor, lqchen@seu.edu.cn.

Foundation item: The National Natural Science Foundation of China (No. 69092008).

Citation: Chen Liquan, Sun Xiaoyan, Lu Miao, et al. Contourlet watermarking algorithm based on Arnold scrambling and singular value decomposition[J]. Journal of Southeast University (English Edition), 2012, 28(4): 386 - 391. [doi: 10.3969/j.issn.1003 - 7985.2012.04.003]

ness performances than the traditional contourlet watermarking algorithm and the contourlet watermarking algorithm with SVD. Its robustness performances against image compression attack, adding noise attack and image cutting attack etc. are outstanding while security and hidings performances are ensured.

1 Contourlet Transform

The contourlet transform includes two steps. First, it uses a multi-scale decomposition such as the wavelet transform to capture the edge singular points of the image. Then, according to the directional information, it collects the singular points under the same direction to obtain the contourlet transform coefficients and capture the image skeleton. These two steps are realized based on Laplacian pyramid (LP) decomposition[9] and directional filter bank (DFB)[10] structure followed by directional filter-banks applied on each sub-band.

The contourlet transform is based on a double filter bank structure. It captures the singular points of the two-dimensional image through sub-band decomposition on the original image. LP decomposition decomposes the original image into low pass predicted components and difference components. This process will repeat on the low pass components at each level until all the low pass components and high pass components are obtained. Then the multiple resolution decomposition of the original image is achieved.

Through the contourlet transform, most energy is gathered into low frequency sub-bands. The low pass components are robust against many sorts of image processes such as compression, cutting and noise adding. However, it also means that any modification on low pass components may lead to large image distortions. Contrarily, the high pass components are less influenced by image processes.

2 Arnold Scrambling and SVD

2.1 Arnold scrambling

The basic concept of the Arnold scrambling is to change the position relationship among pixel points and reduce their correlation in order to meet the demands of image encryption and digital watermarking security.

In general, we consider an image with a two-dimensional function on the plane domain as $\boldsymbol{I} = F(x, y)$, where x and y are coordinates of pixel points in the coordinate system. Arnold scrambling is a scheme to change the position of pixels by modifying their numerical values through a matrix transformation on x and y.

Suppose that there is an image with $N \times N$ size and $x, y \in \{0, 1, 2, \dots, N-1\}$. We conduct the simple Arnold transform to the image as

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} (\bmod N) \tag{1}$$

where x' and y' represent the new positions. Matrix $\begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}$ is a common Arnold transform matrix. We can extend the transform matrix to a more general form as $\begin{bmatrix} a & b \\ c & d \end{bmatrix}$, where a, b, c and d are integers which satisfy the equality $ad - bc = 1$. When the same Arnold transformation is applied to the Arnold scrambled image for several times, the image can return to its origin again.

2.2 SVD scheme

From the viewpoint of linear algebra, an image can be seen as a matrix of many non-negative scalars. Suppose that $\boldsymbol{I} \in \mathbf{R}^{M \times N}$ represents an image with $M \times N$ in size, then the singular value decomposition of $\boldsymbol{I}$ is defined as $\boldsymbol{I} = \boldsymbol{USV}^{\mathrm{T}}$, where $\boldsymbol{U}$ and $\boldsymbol{S}$ are orthogonal matrices, and $\boldsymbol{S}$ is a diagonal matrix whose diagonal elements are not all zero. Here,

$$\boldsymbol{S} = \begin{bmatrix} \delta_1 & 0 & 0 & 0 \\ 0 & \delta_2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \delta_M \end{bmatrix} \tag{2}$$

where $\delta_1 \geqslant \delta_2 \geqslant \delta_3 \geqslant \dots \geqslant \delta_r \geqslant \dots \geqslant \delta_M = 0$, while r is the rank of the matrix.

There are three main features in the SVD scheme: 1) The singular values correlate to the brightness of the image and represent the intrinsic features of the image. 2) The SVD scheme has good stability. When the image is attacked by slight exterior attacks, the singular values of the image will not change. 3) The matrix of singular values is a descending order matrix.

3 Contourlet Watermarking Algorithm

We describe the contourlet transform watermarking algorithm based on the Arnold scrambling and the SVD scheme from embedding and extraction aspects. Suppose that the original carrier image is the "Lina" image with 384×384 pixels, the watermark is a 40×40 two-dimensional binary image. The embedding process and the extraction process are shown in Fig. 1.

3.1 Embedding process

The process of embedding is described as follows:

1) The Arnold scrambling is applied to the watermark matrix. It reconstructs the watermark image to a $1 \times 1\,600$ one-dimensional watermark.

2) The key k is used to create two pseudo random sequences for the embedding process. The two pseudo random sequences are pn_sequence_zero and pn_sequence_one.

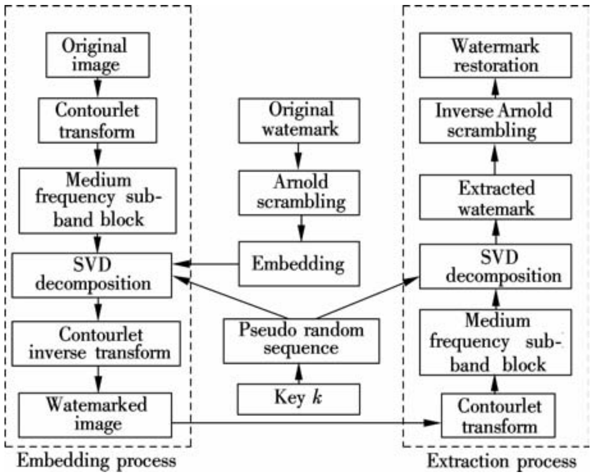

Fig. 1 Contourlet watermarking algorithm based on Arnold scrambling and SVD

3) Then, the contourlet transform is applied to the original carrier image. Suppose that three-level LP decomposition and (3, 2, 3)-level DFB decomposition are applied, and we can obtain (8, 4, 8) high frequency sub-bands.

4) Then, watermark bits are embedded to the four medium frequency sub-bands on the second level after the contourlet transform. We transform the four $a' \times b'$ medium-frequency sub-bands data into a new $2a' \times 2b'$ matrix, named as matrix $\boldsymbol{C}$, and divide the $2a' \times 2b'$ matrix into a new 4×4 block matrix which includes information of each block. Here, a' and b' are the sizes of medium-frequency sub-band components. The new matrix is named as matrix $\boldsymbol{C}'$.

5) The singular value decomposition is applied to the matrix $\boldsymbol{C}'$ and $[\boldsymbol{USV}] = \mathrm{svd}(\boldsymbol{C}')$. Then, the singular value is modified according to the watermark value so as to realize the embedding processing. For example, if the watermark value watermark(i) = 0 (i = 0, 1, …, 1 600), then the pseudo random sequence pn_sequence_zero(i) is added to $s(m, n)$, where $s(m, n)$ means the s value of matrix position (m, n). When watermark(i) = 1, pn_sequence_one(i) is added to $s(m, n)$. This process will repeat until i reaches 1 600. Finally, the elements in matrix $\boldsymbol{C}$ is replaced by the new related element of $\boldsymbol{C}'$.

6) Finally, an inverse contourlet transform is applied to each sub-band and the carrier image with watermark is obtained.

3.2 Extraction process

The extraction process is a semi-blind watermark extracting solution because it realizes the extraction only with the knowledge of the watermark size. When the exact size of the embedded watermark is known, we can calculate the correlation between the SVD values of medium frequency blocks and the two pseudo random sequences to identify what the embedded values are, and the watermark bits are restored.

The steps of the extraction are as follows:

1) to 3) steps are the same as 2) to 4) steps in the embedding process. Then, we obtain $[\boldsymbol{U}\ \boldsymbol{S}\ \boldsymbol{V}] = \mathrm{svd}(\boldsymbol{C}')$.

4) The correlation coefficients between the singular values of each block and the corresponding pseudo random sequence values are calculated, and then we obtain the correlation_zero(i) values and correlation_one(i) values, respectively. If the correlation_zero(i) > correlation_one(i), the extracted watermark value watermark(i) = 0; otherwise, the watermark(i) = 1.

5) The watermark is reconstructed to a 40×40 matrix and the Arnold inverse scrambling processing is used to obtain the embedded watermark image.

4 Simulation and Results Analysis

The performance evaluations of digital watermarking include the peak signal-to-noise ratio (PSNR) performance and the normalized correlation (NC) coefficient performance [11].

The PSNR performance is used to evaluate the hiding performance of the digital watermarking algorithm and it is defined as

$$\mathrm{PSNR} = 10\lg \frac{MN\max\{\boldsymbol{I}^2(i,j)\}}{\sum_{i=1}^{M}\sum_{j=1}^{N}(\boldsymbol{I}(i,j) - \boldsymbol{I}'(i,j))^2} \tag{3}$$

where $\boldsymbol{I}$ represents the original carrier image with $M \times N$ in size, and $\boldsymbol{I}'$ is the new image with the embedded watermark. In general, the larger the PSNR value, the smaller the influence of the embedded watermark on the carrier image.

The NC is used to represent the similarity between the extracted watermark and the original one. It is defined as

$$\mathrm{NC}(\boldsymbol{W}, \boldsymbol{W}') = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\boldsymbol{W}(i,j)\boldsymbol{W}'(i,j)}{\sum_{i=1}^{M}\sum_{j=1}^{N}\boldsymbol{W}(i,j)^2} \tag{4}$$

where $\boldsymbol{W}$ is the original watermark image and $\boldsymbol{W}'$ is the extracted one. In general, the larger the NC value, the more similarity between the original image and the extracted one.

4.1 General simulation results

The carrier image is a 384×384 "Lena" image and the watermark image is a 40×40 binary image. The embedding strength $f = 0.9$. The Arnold scrambling times are 4 and the inverse Arnold scrambling times are 26. We simulate the traditional contourlet watermarking algorithm (referred as the traditional contourlet) proposed in Ref. [5], the contourlet watermarking algorithm with the SVD (referred as contourlet + SVD) proposed in Ref. [6] and the proposed contourlet watermarking algorithm with Arnold scrambling and SVD (referred as contourlet + Arnold + SVD). In the contourlet + Arnold + SVD algorithm, Arnold scrambling is applied to the watermark image first. Then LP decomposition and (3, 2, 3)-level DFB decomposition are applied to the original carrier image. Watermark bits are embedded to the medium frequency coefficients of the sub-band matrices after SVD matrix decomposition. Fig. 2 presents the original carrier image and the watermark image. Then, the images with watermark and the extracted watermarks of the traditional contourlet algorithm, the contourlet + SVD algorithm and the contourlet + Arnold + SVD algorithm are shown in Fig. 3, Fig. 4 and Fig. 5, respectively. Here the watermark image in Fig. 2(b) is zoomed in to present more detail. The watermarks in Fig. 3(b), Fig. 4(b) and Fig. 5(b) are also zoomed in.

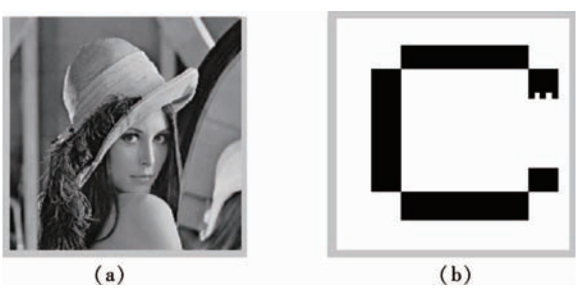

Fig. 2 Original simulation images. (a) Original carrier image; (b) Original watermark

Fig. 3 Simulation results of the traditional contourlet algorithm. (a) Image with watermark; (b) Extracted watermark image

Fig. 4 Simulation results of the contourlet + SVD algorithm. (a) Image with watermark; (b) Extracted watermark image

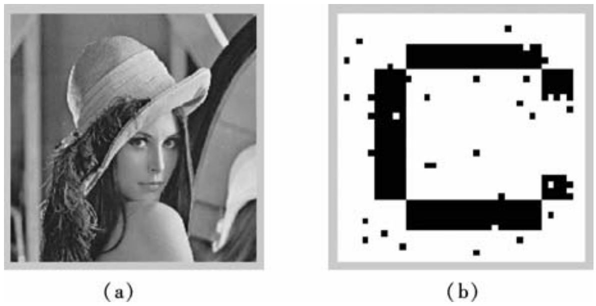

Fig. 5 Simulation results of the contourlet + Arnold + SVD algorithm. (a) Image with watermark; (b) Extracted watermark image

When the embedding strength f is 0.9, the PSNR values and NC values of the three algorithms are obtained and presented in Tab. 1.

Tab. 1 Comparison of PSNR and NC among the three algorithms

Algorithm	PSNR value	NC value
Traditional contourlet	37.171 2	0.948 1
Contourlet + SVD	38.213 9	0.963 4
Contourlet + Arnold + SVD	40.916 6	0.982 3

From Tab. 1, we see that the PSNR and NC performances of the proposed contourlet + Arnold + SVD algorithm outperforms the performances of the traditional contourlet algorithm and the contourlet + SVD algorithm.

4.2 Hiding performances

In the above simulations, we set the embedding strength f to be 0.9. Now, we change the f value and obtain different PSNR values to compare the hiding performances of those three watermarking algorithms. The simulation results are shown in Fig. 6.

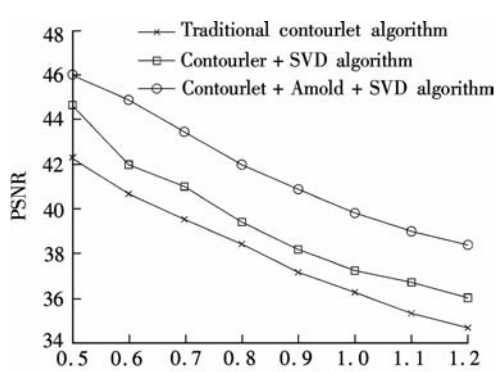

Fig. 6 PSNR performances of the three algorithms in different embedding strengths

The hiding performance of digital watermarking is mainly evaluated with PSNR values. The results show that with the increase in embedding strength, the PSNR values of the three contourlet digital watermarking algorithms all decrease. However, the PSNR values of the contourlet + Arnold + SVD algorithm are always higher than those of the traditional contourlet algorithm and the contourlet + SVD algorithm. The reason is that the contourlet + Arnold + SVD algorithm is based on the dispersing features of the Arnold scrambling and the intrinsic features of the SVD scheme in image processing.

4.3 Robustness performances

In this simulation, salt and pepper noise, Gaussian noise and multiplicative noise are respectively applied to the carrier images with the embedded watermark by these three algorithms. Moreover, the image scaling attack and image cutting attack are also applied to the watermark carried images. The NC values of the traditional contourlet algorithm, contourlet + SVD algorithm and the contourlet + Arnold + SVD algorithm against different attacks are shown in Fig. 7.

Furthermore, the performances of the proposed contourlet + Arnold + SVD algorithm against image compression attacks are evaluated. Suppose that the image with the embedded watermark are conducted with JPEG compression, the compressing rate changes from 80% to 50%. The extracted watermarks and NC values from the simulation are shown in Tab. 2. We find that the proposed contourlet + Arnold + SVD algorithm has good robustness against image compression attacks.

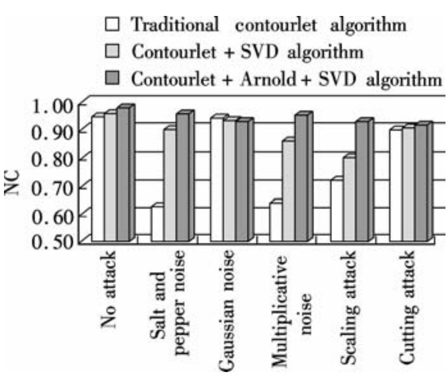

Fig. 7 Robustness performances of the three algorithms against different attacks

Tab. 2 Simulation results of contourlet + Arnold + SVD algorithm against different compression attacks

Compression rate	80%	70%	60%	50%
NC value	0.978 1	0.963 4	0.957 3	0.938 6
Extracted image				

Generally, the proposed digital watermarking algorithm based on the Arnold scrambling and the SVD scheme have higher NC values against many sorts of attacks, which means that the similarity between the original watermark and the extracted one is good. Furthermore, the performances of the proposed contourlet + Arnold + SVD algorithm are better than the traditional contourlet algorithm and the contourlet + SVD algorithm in many attack environments, especially in the instances against salt and pepper noise attack and multiplicative noise attack. However, when confronted with the Gaussian noise attack, the performance of the proposed contourlet + Arnold + SVD algorithm is a little weak because the dispersing of the Arnold scrambling technique has a negative effect on the Gaussian noise attack instance. However, the proposed contourlet + Arnold + SVD watermarking algorithm has enhanced performances in many cases against other watermarking attacks. It has good robustness while hiding performance is ensured.

5 Conclusion

Since the digital watermarking algorithm based on the contourlet transform is increasingly becoming an important technology in the digital research field, this paper presents a new contourlet transform digital watermarking algorithm. The algorithm uses Arnold scrambling to reduce the image correlation for security improvement and uses the stability of SVD coefficients for watermark embedding to improve robustness. The proposed contourlet digital watermarking algorithm, which is based on the Arnold scrambling technique and the SVD, chooses the largest energy block in medium frequency sub-bands as embedding points to balance the demands of robustness and hiding performance. Simulation results prove the validity of the proposed algorithm.

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基于 Arnold 置乱及 SVD 的 Contourlet 数字水印算法

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摘要：为了提高数字水印的鲁棒性和抗攻击能力，提出了一种基于 Contourlet 变换的新型数字水印算法. 该方法从水印预处理和嵌入方式 2 个方面入手，用 Arnold 置乱来预处理水印数据，通过对载体图像进行奇异值分解（SVD）处理来寻找最合适的嵌入位置. 载体图像经过 Contourlet 变换后，对中频子带进行 SVD 分解以得到 SVD 数值，将 Arnold 置乱后的水印分散嵌入到中频子带的 SVD 参数中，再经过 Contourlet 反变换得到嵌入水印后的载体图像. 在提取端，Contourlet 水印的提取采用半盲检测提取方法. 仿真结果表明，与传统 Contourlet 算法和结合 SVD 的 Contourlet 算法相比，所提出的算法具有更好的隐藏性能和鲁棒性. 同时，在保证安全性能的基础上，当嵌入的水印受到高斯噪声、椒盐噪声、图像扩展、图像剪裁等攻击时，所提算法具有良好的鲁棒性能.

关键词：数字水印；Contourlet 变换； Arnold 置乱；奇异值分解

中图分类号：TP309.2