

An Optimal Digital Watermarking Algorithm in Curvelet Domain

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Abstract. An optimal digital image watermarking algorithm in Curvelet domain based on singular value decomposition (SVD) and genetic algorithm (GA) is proposed in this paper. The watermark is firstly encrypted by Arnold transform. Then, the low frequency part in Curvelet domain of the host image is divided into blocks, and with SVD processing to every block, pixel values of scrambled watermark are embedded into largest singular values of blocks respectively by quantization index modulation method. Moreover, by GA to optimize quantification step our algorithm makes a tradeoff between robustness and invisibility. The watermark can be detected without the original image. The experimental results show that the algorithm is robust to JPEG compression, noise, cropping etc. attacks. The proposed hybrid algorithm can properly meet imperceptibility and robustness.

Introduction

Copyright protection of the digital image is one of challenging issues imposed in ubiquitous media. Digital watermarking is a kind of technology that embeds copyright information into multimedia data[1]. Watermark technology should meet authentication, imperceptibility, robustness and security basic features. But these features often conflict with each other and need to reach a tradeoff.

Watermark embedding can be done in spatial domain and frequency domain. Frequency method is seen in discrete cosine transform(DCT), discrete wavelet transform(DWT), Framelet transform[2] and so on. Although the spatial domain watermark embedding is simple and easy to implement, it is less robust than frequency domain watermark embedding against many common attacks.

Curvelet proposed by E. Candès and D. Donoho in 1999 can be seen as an extension of wavelet for multidimensional data[3]. Compared with wavelet, Curvelet is more suitable for image processing as it is able to represent edges and other singularities along curves more efficiently. Singular value decomposition(SVD) is one of the most useful tools of linear algebra with applications in image compression, watermarking, and other signal processing fields. And the SVD-based watermarking algorithm shows strong robustness to common geometric distortions[2,4].

In our work the watermark is embedded to the Curvelet domain combining with SVD and quantization modulation method. Moreover, we apply genetic algorithm(GA)[5] to search for the optimal quantification step to improve the quality of the watermarked image.

The Optimal Digital Watermarking Algorithm

In this session, we firstly introduce the theoretical basis of the algorithm briefly, and then introduce the implementation of the algorithm in detail.

Curvelet transform[3,6] is a higher dimensional generalization of the wavelet transform designed to represent images at different scales and different angles. Curved singularities can be well approximated with very few coefficients and in a non-adaptive manner. In 2005, E. Candès [6] etc. proposed fast discrete Curvelet transform(FDCT) based on second generation Curvelet transform. Two distinct implementations are wrapping-based transform and transform using unequally-spaced fast Fourier transform (USFFT) [7]. Arnold transform proposed by V. I. Arnold has widely applied in digital image encryption because of its periodicity[2]. We perform Arnold transform to scramble the watermark that can enhance the robustness for example resistance cropping attack and provide

security to the watermark from unauthorized access. Singular value decomposition(SVD) is a linear algebra tool. By the algebraic properties of SVD , ZHOU B. [4]etc. prove that singular values of the watermarked image are invariant when it goes through the geometric distortions of transpose, mirror reflection, rotation, scale, and translation. Because of these properties, SVD is used as a tool to develop the watermarking scheme. GA[5] is a kind of best searching algorithm that simulates biological evolution to produce a similar optimal solution and widely used in various fields. Determining proper quantization step to reach a tradeoff between robustness and imperceptibility is viewed as an optimization problem in our work and we use GA to search the feasible solution.

The diagram in Fig.1 illustrates the optimization process of our algorithm. Details are as follows.

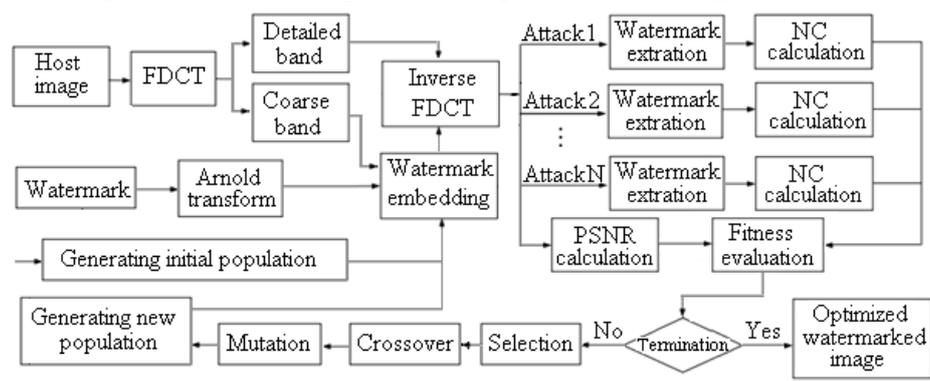


Fig. 1 the proposed watermarking scheme

Step 1. Perform Arnold transform on watermark image denoted by W and get scrambled watermark matrix denoted by W_s with size of $m \times n$.

Step 2. Convert host image denoted by I to Curvelet domain through FDCT. Host image is decomposed into some cells of Curvelet coefficients i.e. a coarse band coefficients denoted by A with size of $m_h \times n_h$ and some detailed band coefficients include detail and fine coefficients.

Step 3. Divide the coarse coefficient matrix A into nonoverlapping blocks denoted by $A_{i,j}$ ($1 \leq i \leq m, 1 \leq j \leq n$) whose size is according to the watermark i.e. the size of block is $\lfloor m_h/m \rfloor \times \lfloor n_h/n \rfloor$.

Step 4. Perform SVD transform on each block divided in Step 3, i.e. $A_{i,j} = U_{i,j} \Sigma_{i,j} V_{i,j}^T$. Then the largest singular value $\Sigma_{i,j}(1,1)$ ($1 \leq i \leq m, 1 \leq j \leq n$) of each block are collected together to get a new matrix of the largest singular value denoted by S with size of $m \times n$.

Step 5. Set size of population denoted by Q , range of population and maximum generations. And then generate the number of Q initial GA individuals which stand for different quantification steps and influence the watermarking embedding intensity.

Step 6. Execute the embedding procedure with the GA individuals one by one. (Q different watermarked images will be generated in this step.) The embedding details which change matrix S ($S = \{ S_{i,j} \}$) obtained in step 4 into new matrix S^* ($S^* = \{ S_{i,j}^* \}$) are as follows.

- a. Get $Z_{i,j} = S_{i,j} \bmod q$, ($1 \leq i \leq m, 1 \leq j \leq n$), q i.e. quantification step is individual of the population.
- b. When the value of the scrambled watermark W_s is zero:

$$\text{if } Z_{i,j} \in [0, 3q/4) \quad S_{i,j}^* = S_{i,j} + q/4 - Z_{i,j}, \text{ else } S_{i,j}^* = S_{i,j} + 5q/4 - Z_{i,j}$$

- c. When the value of the watermark W_s is nonzero:

$$\text{if } Z_{i,j} \in [0, q/4) \quad S_{i,j}^* = S_{i,j} - q/4 - Z_{i,j}, \text{ else } S_{i,j}^* = S_{i,j} + 3q/4 - Z_{i,j}.$$

- d. Map $S_{i,j}^*$ to $\Sigma_{i,j}^*$ and get a new $\Sigma_{i,j}^*$ ($1 \leq i \leq m, 1 \leq j \leq n$). Perform inverse SVD transform for each block based on $U_{i,j}$, $\Sigma_{i,j}^*$ and $V_{i,j}^T$ to get $A_{i,j}^*$. And then further obtain watermark embedded coarse band denoted by A^* .

- e. Perform inverse FDCT to obtain the embedded image.

Step 7. Calculate the fitness values for each individual. The fitness function in GA is determined by imperceptibility and robustness of the algorithm together. Details are as follows.

a. Calculate the peak signal-to-noise ratio (PSNR) [2] value. The watermarked image quality is measured by the *PSNR* between host image and watermarked image. The larger *PSNR* value, the more imperceptible the watermarked image is. *PSNR* is regarded as the measure for imperceptibility.

b. Calculated *NC*. Attack the embedded image using the selected methods. Extract out the watermarks of these different attacked images. And last calculate normalized cross-correlation (*NC*) value for each extracted attacked watermark and original watermark, as described next.

Extract watermark at first. Perform same FDCT as step 2 to attacked watermarked images, and then apply SVD to each block divided as step 3. Get a new matrix denoted by S' by collected the biggest singular values of blocks together. The possible distorted scrambled watermark denoted by W^S is extracted through $Z' = S'_{i,j} \bmod q$. If $Z' \in [0, q/2)$, $W_{i,j}^S = 0$, else $W_{i,j}^S = 1$. Perform reverse Arnold transform for W^S using the same as step 1 secret key to reconstruct watermark W' . Then calculated *NC* value. *NC* measures the correlation between the extracted and the original watermark. *NC* is calculated according to the formula (1):

$$NC(W, W') = \frac{\sum_{i=1}^m \sum_{j=1}^n W(i, j)W'(i, j)}{\sqrt{\sum_{i=1}^m \sum_{j=1}^n W^2(i, j)} \sqrt{\sum_{i=1}^m \sum_{j=1}^n (W'(i, j))^2}} \quad (1)$$

where W and W' denote the original and the extracted watermark images, respectively. m and n are watermark image length and width respectively. *NC* is used to evaluate robustness of watermark. The larger the *NC* value, the more robustness of the watermarked image.

c. Calculate the fitness value for different individual according to the Eq. 2.

$$f_i = \alpha \times PSNR_i + \beta \times \sum_{j=1}^m NC_j^i, 1 \leq i \leq Q \quad (2)$$

where α and β are weighting factors of *PSNR* and *NC* respectively. Each weighting factor represents how important each index is during the searching process of the proposed method. m is the total number of attacks. i is sign of different individuals.

Step 8. Judge whether termination criteria has been satisfied. If it hasn't done, select individuals from the old population based on the fitness of individuals as given by evaluation function. And then apply crossover and mutation operators to members of the population to create the new solution and repeat Step 6~8. Else, obtain optimal quantification step, and output optimized watermarked image.

The above eight steps can achieve the watermark embedding. The watermark extraction of our algorithm is the same method in step 7. It is blind extraction.

Experiment Result and Analysis

Several experiments have been carried out to verify the validity of the proposed watermarking algorithm. In this paper the gray image Lena with size 512×512 pixels and 32×32 pixels binary image are used as the host image and the watermark which are illustrated in Fig.2(a) and (b) respectively. Host image performs three level wrapping-based transform. The secret key to arnold transform for watermark image is 8, and corresponding result is show in Fig.2(c). Genetic Algorithm for Optimization Toolbox(GAOT) is used to generate populations and search the optimal solution. Eight differernt attacks are simulated and the parameter α and β in fitness function in Eq.2 are 0.08 and 0.124 respectively. The range of population member is set between 40 and 160, and the population size is 20 and 50 generations are done to terminate the GA and the probability of mutation are 0.08. The optimal solution of the quantization step parameter q is 67.5 and the corresponding optimal watermarked image is show in Fig.2(d). In subjective, it seems difficult to distinguish the difference between the host image and the watermarked image by the human eye.

The watermarks which are extracted from the optimal watermarked image and eight different attack to the optimal watermarked image are illustrated in Fig.3. From the experimental results, we find even if the watermarked image has undergone attacks, the proposed method can still extract the correct watermark or determine the existence of the watermark.

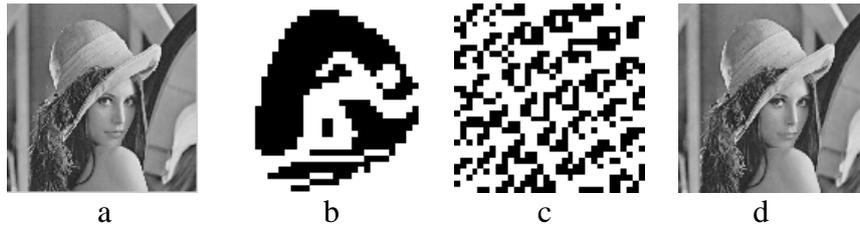


Fig.2 (a)host image (b)watermark (c) scrambled watermark (d)optimal watermarked image

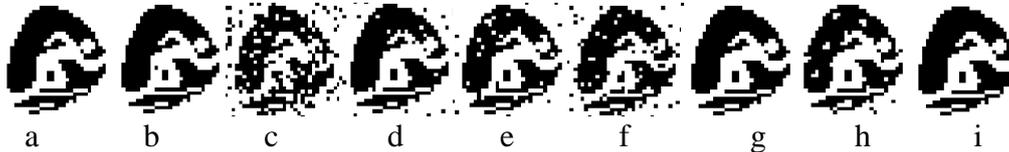


Fig.3 extracted watermarks (a)JPEG compression at 70% (b)JPEG compression at 40% (c)Gaussian noise with zero mean and 0.002 variance (d)salt pepper noise with zero mean and 0.002 variance (e) 3×3 median filter (f)3×3 average filter (g)3×3 Gaussian low pass filter with zero mean and 0.5 standard deviation (h) 128×128 cropping (i) no attacks

Table 1 lists *PSNR* value of optimal watermarked image and *NC* values of watermarks corresponding to the Fig.3. It shows that our approach can obtain high *PSNR* value and extracted watermarks with relatively satisfactory *NC* values. Robustness of this method can be shown in experiments.

Tab.1 the experimental data aiming at the optimal watermarked image

<i>PSNR</i>	<i>NC</i>								
	JPEG (0.7)	JPEG (0.4)	Gaussian noise	Salt pepper noise	median filter	average filter	Gaussian low pass filter	cropping	No attacks
46.57	1	0.9992	0.8855	0.9746	0.9701	0.9465	0.9992	0.9707	1

Conclusions

In this paper, we use GA to adaptively search the quantification step. By quantization index modulation method to embed scrambled watermark into largest singular values which are obtained by SVD processing to the divided blocks of low frequency part in Curvelet domain of the host image. It actualizes self-adaptive embedding and blind extraction. The experiments show the new proposed algorithm can attain the tradeoff between robust and imperceptibility. This optimal watermark watermarking embedding design can effectively improve the practicability of the algorithm.

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