Watermarking in halftone image with maximal child node dependence coefficients in wavelet domain

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Abstract. To achieve high image quality, this paper proposes a novel approach but efficient algorithm for halftoning watermarking. Wavelet coefficients of edge details have strong relations, while the dependence of coefficients of texture is more weak. On the other hand, large wavelet coefficients contain the information of image brink. Considering the relationship of intra-scale and maximal coefficients, the boundary error measure is built. While the gray image turns to halftone image using proposed algorithm, binary watermark is embedded in the edge position. In order to enhance the ability to resist cropping and smearing attack, the watermark image is pre-treated with Arnold transformation processing. The proposed method is effective, because the halftone image is embedded as a watermark sequence during the halftone process. Experiment results show that this algorithm does not cause significant distortion of the image and is good resistance to cropping, daub, JPEG compression and noise attacks.

1. Introduction

Halftone is known as gray-scale and a technical indicator which reflects the image brightness level and the black and white contrast changes. Binary halftone image would try to compute a pattern of binary dots to achieve the illusion of a multi-bit image.

The halftoning algorithms can be further classified through various properties and features, including point based methods, such as screening [1], neighborhood based methods, such as error diffusion [2-5], iteration-based scheme such as Direct Binary Search (DBS) [6-8] and lookup based scheme such as Look Up Table (LUT) halftoning [9]. Iterative optimization methods use a human visual system model to minimize the perceived error [10]. Although all halftoning methods rely on some understanding of the properties of human vision and the display device, the goal of model-based halftoning techniques is to exploit explicit models of the display device and the human visual system (HVS) to maximize the quality of the displayed images [11].

However, the best halftone reproductions are obtained via iterative techniques that minimize the error between the continuous tone image and halftone image. They include one-dimensional Viterbi algorithm which to obtain the globally optimal solution [12], blocking with branch and bound minimization [13], diffusion-reaction model [14]. The LSMB halftoning approach attempts to produce an optimal halftone reproduction [15].

Digital watermarking has many applications, such as protecting the ownership rights of an image, tracking unauthorized uses of a work as in fingerprinting, or authenticating the originality of an image,
that it has not been tampered with. Since the halftoning is widely used, halftone-based watermarking methods have been studied in recent years. The methods normally require higher computational complexity and produce higher image quality. These methods include using the concept of vector quantization to embed watermark into the most or least significant bit of an error-diffused image [16]. In [17], different dither cells were exploited to create a threshold pattern in the halftoning process, in which each dither cell represents the corresponding information bit of the watermark. In [18], the modified data-hiding error diffusion method was employed to embed data into an error-diffused image. In [19], the DBS was employed to achieve halftoning and watermarking simultaneously.

2. The halftoning of scales correlation coefficients fusion

For an input represented by a list of $2^n$ numbers, the Haar wavelet transform may be considered to simply pair up input values, storing the difference and passing the sum [16]. This process is repeated recursively, pairing up the sums to provide the next scale, finally resulting in $2^{n-1}$ differences and one final sum.

Let $\phi^{LL}$ denote scale function, {$\phi^{LH}, \phi^{HL}, \phi^{HH}$} denote wavelet function. The scale function and wavelet function form $L^2(R^2)$ space orthogonal basis. For a given image $f(x,y)$ is decomposed in the space domain, which the size of $N \times N$. It can be expressed as

$$f(x,y) = \sum_{i,j=0}^{N-1} u_{i,j} \phi^{LL}_{i,j}(x,y) + \sum_{i,j=0}^{N-1} \sum_{b \in B} w_{j,k_i}^{b} \phi^{b}_{j,k_i}(x,y)$$

(1)

Where $b \in B$, $B = \{LH, HL, HH\}$ is the wavelet coefficients in three directions sub-band, $N_j = N/2$. The scale coefficients $u_{j,k_i}$ and wavelet coefficients $w_{j,k_i}$ in $j$ scale sub-band $B$ direction. The multiscale information are show as Figure 1 (b).

![Figure 1](image_url)

(a) (b)

**Figure 1.** The Original Image and the DWT (a) Original Image (b) Four Levels DWT

Upon the assumption that the wavelet coefficients are mutually independent, they are normalized. The boundary information of the image target is fused by the wavelet coefficients of the correlation between wavelet transform layers, which to increase the pixel resolution scale. We apply the inter-scale fusion method to gain fusion coefficient of the fine-scale, which take into account the detail of the image and approximate information. The fusion information of wavelet coefficients inter-scale is shown in Figure 2.
Figure 2. The Fusion Information of Wavelet Coefficients Inter-scale for HL, LH and HH Sub-band (a) HL (b) LH (c) HH

We will use the term contrast sensitivity here, since we have used this terminology throughout Mannos and Sakrison [18] proposed a model of the human contrast sensitivity function, which found the following filter frequency response to be good for predicting the subjective quality of coded images.

\[ H_r(f_r) = 2.6(0.0192 + 0.114 f_r) \exp\left\{-(0.114 f_r)^{1.1}\right\} \]  

(2)

Where \( f_r \) is the spatial frequency of the visual stimuli given in cycles/degree. The function has a peak of value 1 approximately at \( f_r = 8.0 \) cycles/degree, and is meaningless for frequencies above 60 cycles/degree.

Least-squares model-based (LSMB) halftoning attempts to produce an optimal halftone reproduction [15]. The gray level of each pixel varies from 0 equal to white to 1 equal to black.

Assuming that the image has been sampled so there is one pixel per dot to be generated. Thus the gray-scale image array \([x_{i,j}]\) and the binary image array \([h_{i,j}]\) have the same dimensions. We are also given a printer model with the sliding-window form and an eye model of the form with a memory-less nonlinearity \( n(\cdot) \) followed by an FIR filter with impulse response \([h_{i,j}]\). In the LSMB approach we seek the halftone image that minimizes the squared error.

Weighted least squares model-based regression is useful for estimating the values of model parameters when the response values have differing degrees of variability over the combinations of the predictor values [19]. Optimal results that minimize the uncertainty in the parameter estimators are obtained when the weights used to estimate the values of the unknown parameters are inversely proportional to the variances at each combination of predictor variable values. \( \lambda_i \propto 1/\sigma_i^2 \).

In the proposed approach, we seek the halftone image that minimizes the weighted squared error. The related descriptions are formulated as below

\[ E_{i,j} = \left\{ \sum_{l=1}^{4} (LH, HL, HH) + \sum_{k=1}^{4} \lambda_k \right\} \sum_{i,j} (z_{i,j} - w_{i,j})^2 \]  

(3)

Note that we have allowed different impulse responses for the eye filters corresponding to the halftone and continuous-tone images. The halftoning image is show as Figure 3.

Figure 3. The Halftone Image
3. Watermark embedding and detection scheme

3.1. Arnold transformation processing

Image scrambling may transfer the image into an unorganized, which can't gain intuitive information. Therefore, the image is encrypted by scrambling transformation that enhanced the security of information. At the same time, scrambling transformation has a strong resistance to cropping and paint attack. Images matrix are transformation using Arnold transformation. In this paper, it used Arnold transformation to encrypt the watermark image, then inserted the watermark image into the important coefficients from different orientations of the wavelet transformation.

The watermark image is seen as a dual function on the flat area \( G = F( x, y) \), \((x, y) \in \mathbb{R}\). For arbitrary point \((x, y)\) in \(\mathbb{R}\), then \(F(x, y)\) is on behalf of image information, (such as the gray value, etc.). \(G = F(x, y)\) is equivalent to a two-dimensional discrete lattice when the watermark image is digital. For digital image pixel coordinates \((x, y)\) \(\in \{1, 2, \ldots, N\}\). So, Arnold transform is:

\[
\begin{bmatrix}
    x' \\
    y'
\end{bmatrix} = \begin{bmatrix}
    1 & 1 \\
    1 & 2
\end{bmatrix} \begin{bmatrix}
    x \\
    y
\end{bmatrix} \pmod{N}
\]

The result of iterative process is expressed as:

\[
P_{xy}^{n+1} = A P_{xy}^n \pmod{N}, P_{xy}^n = (x, y)^T, n = 0, 1, 2, \ldots
\]

where, \(n\) is the number of iterations, the iteration process is cyclical.

3.2. Arnold transformation processing Watermark embedding scheme

In order to enhance the security and robustness of watermark information, the scrambling image is gained after Arnold transform of binary watermark image. Arnold scrambling times \(n\) is a “secret parameter”. This means that receiver will not be able to generate original information if it does not know this parameter. Watermark and scrambling image are shown in Figure 4.

![Figure 4. Arnold Transformation](image1)

![Figure 5. Embedded Watermark Halftone Image](image2)

(a) 32×32 Original Image

(b) \(n=10\) Arnold Transformation

The watermark is embedded the edge of halftone image during the halftone processing, which are the optimal positions for watermark embedding. They are referred to as the key to the receiver. Ultimately embed watermark halftone image is shown as Figure 5.

3.3. Watermark extraction scheme

Firstly, our watermark detection scheme uses watermark key to determine watermark embedding position and extract the watermark value. Secondly, The extract watermark image is Arnold transform
using watermark key and Arnold periodic table. Lastly, the embedded watermark in the halftone image become multi-tone image after the JPEG compression and add Gaussian noise. The embattled image is must binarization (choose threshold is 128) before extracting the watermark.

4. Experimental results and discussions

We test the proposed watermarking scheme on the popular test image 256×256 bit goldhill, as shown in Figure 1(a). The corresponding halftone images are generated by the fusion of scales correlation coefficients, as shown in Figure 3. We embed the watermark in the perceptually highly edge region, so the embedded watermark is less visible. Besides, the MSEv(mean square error value) and PSNR(peak signal-to-noise ratio) are used to measure the visual quality of the watermark halftone image. The visual quality valuation is show as Table 1.

| Test image | MSEv | PSNR(dB) |
|------------|------|----------|
| goldhill   | 0.14 | 40.98    |

Here is the list of the different attacks, including Noise addition, JPEG compression, Cropping, Daub and Rotations, which are shown in Figure 6, 7, 8, 9 and 10, respectively.

Figure 6. The Simulation Results for Noise Addition Obtained by Using the Proposed Scheme (a) Noise Addition (b) Watermark Extraction (c) Arnold Inverse Transformation

Figure 7. The Simulation Results for JPEG Compression Obtained by Using the Proposed Scheme (a) Noise Addition (b) Watermark Extraction (c) Arnold Inverse Transformation

Figure 8. The Simulation Results for Cropping Obtained by Using the Proposed Scheme (a) Noise Addition (b) Watermark Extraction (c) Arnold Inverse Transformation

Figure 9. The Simulation Results for Daub Obtained by Using the Proposed Scheme (a) Noise Addition (b) Watermark Extraction (c) Arnold Inverse Transformation
Figure 10. The Simulation Results for Rotations Obtained by Using the Proposed Scheme(a)Noise Addition(b)Watermark Extraction(c)Arnold inverse Transformation

Table 2 summarize the detection results against several attacks. In this paper, we use the term “normalized cross-correlation, NC” to denote it. The NC value are 0.768, 0.991, 0.891, 0.984 and 0.935 between the extraction and original watermark, respectively.

Table 2. NC of detected watermark under several attacks

| Attacks          | NC   |
|------------------|------|
| noise addition   | 0.768|
| JPEG compression | 0.991|
| cropping         | 0.891|
| daub             | 0.984|
| rotations        | 0.935|

The experimental results show that the image of error is spread out using Arnold transform. After the watermark pre-processing by Arnold, watermark can be able to resist clipping and daubing attack, the robustness of watermark is better. In the case of halftone image quality significantly decreased, extraction watermark can identify. Use proposed algorithm for edge enhance, invisibility of watermark is better in the edge position of the embedded watermark.

5. Conclusions

In many applications, it is desirable to embed data in halftone images, but the existing halftone image watermarking has the shortcomings of being not able to guard against attacks caused by cropping, daubing, noise and rotation, etc. In this paper, we proposed a digital method with Maximal Father-Child Node Dependence Coefficients in Wavelet Domain for halftone image with good visual quality. Experimental results show that the proposed scheme is robust against several attacks. At the edge of the halftone image, position watermark has good invisibility.

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