Journal of Shanghai University (English Edition), 2003, 7(4): 384~388
Article ID: 1007-6417(2003)04-0384-05

Spatial Domain Technique for Visible Watermarking

Peter Adjei Fordjour, *WANG Shuo-Zhong*(王朔中)
School of Communication and Information Engineering, Shanghai University, Shanghai 200072, China

Abstract A new technique for embedding visible watermarks into a digital image is described in this paper, which uses statistical properties of each pixel and its immediate surrounding pixels in the host image, and also the statistical properties of the host image and that of the image to be embedded (watermark), as the pixels in the host image are replaced one by one by the pixels in the watermark image. The aim is to establish a relationship between pixels in the images that will make the embedded watermark robust and semi-transparent, and to minimize errors caused by watermark addition and subtraction. Also, the original image can be completely reconstructed from the watermarked images.

Key words image, visible watermark, represented standard deviation.

1 Introduction

In digital libraries there is the need to develop effective techniques applied to the images to protect copyright. Digital watermark that is visible, robust and difficult to remove is therefore added to images to discourage copyright infringement[1]. Though visible watermarking reduces the commercial value of the host-information, it does not however attract pirates thus preventing the image from theft[1-6]. Many researches have been carried out on digital watermarking. Fewer studies, however, have been reported on visible watermarking as compared to invisible watermarking[2]. Most of the existing techniques on visible watermarking are based on transform domain algorithms, this is because transform domain techniques are said to be more robust than the spatial domain techniques[1], however, there are problems with some of the transform domain algorithms that may result in visual discontinuity[7].

The main aim of this work is to present a technique for visible watermarking in the spatial domain which embeds a mark image to the host image according to the statistical properties of the pixels in the host and the mark images. Error caused by mark addition and subtraction is minimized[6]. For this method, the original host image is not required for the mark extraction. A key is applied to the watermarked image to remove the watermark without introducing perceivable distortion. This feature is desirable for applications in which a visibly watermarked image is used for previewing, and a version with an invisible watermark then supplied when a deal is made. The proposed method is robust in the sense that the embedded watermark cannot be removed without the key.

Received Dec.30, 2002; Revised Jun.11, 2003
Project supported by the National Natural Science Foundation of China(Grant No.60072030) and the Key Disciplinary Development Program of Shanghai(Grant No.2001-44)
Peter Adjei Fordjour, Master Candidate, E-mail:adjeifordjour@yahoo.com
WANG Shuo-Zhong, Ph.D., Professor, E-mail:shuowang@yc.shu.edu.cn

2 Algorithm

2.1 Smoothing

If an image is divided into blocks, the standard deviation of smooth (or almost smooth) blocks is equal to zero (or close to zero). In the same way if the value of a pixel in an image is equal or close to the values of its surrounding pixels then the standard deviation calculated for the small part of the image is zero or close to zero.

If the part of the host image to be watermarked is of the size $m \times n$, we can use this property and calculate the standard deviation of each pixel within its immediate surrounding pixels and call it represented standard deviation (RSD) of the pixel. For a pixel $I_M(i,j)$ in an image IM, the RSD calculated is the minimum if the pixel is equal to the average of its immediate surrounding pixels, $I_M'(i,j)$. Replacing $I_M(i,j)$ with $I_M'(i,j)$ makes the part of the image smooth and therefore the RSD becomes minimum. We use this method to replace all the pixels in a host image (the part to be watermarked) with the average of its surrounding pixels to make the image smooth thus reducing the RSD, calculate the minimum RSD and call it the threshold standard deviation of the pixel.

2.2 Calculations

For each pixel in the host image IM (the part to be covered by the watermark image):

(1) Calculate the standard deviation $\sigma_T(i,j)$ to represent the (minimum) threshold standard deviation for the pixel $I_M(i,j)$. $\sigma_T(i,j)$ is calculated by first replacing the pixel $I_M(i,j)$ with $I_M'(i,j)$, the average of its immediate surrounding pixels.

(2) Calculate the standard deviation, $\sigma_W(i,j)$, for all the pixels in the watermark WM, to represent the standard deviation for the pixel $W_M(i,j)$ replacing $I_M(i,j)$. $\sigma_W(i,j)$ is calculated by replacing pixel $I_M(i,j)$ in the host image with its corresponding pixel $W_M(i,j)$ in the watermark. Numbers of surrounding pixels used in the calculation for different pixel types are given in Table 1.

(3) Calculate

$$\sigma_{WT}(i,j) = \sigma_W(i,j) - \sigma_t(i,j) \tag{1}$$

(4) Normalize $\sigma_{WT}(i,j)$ to generate $\beta(i,j)$ using the equation

$$\beta(i,j) = \frac{\sigma_{WT}(i,j) - \sigma_{T\,\min}}{\sigma_{W\,\max} - \sigma_{T\,\min}} \tag{2}$$

where $\sigma_{T\,\min}$ and $\sigma_{W\,\max}$ are the minimum and maximum values of $\sigma_T(i,j)$ and $\sigma_W(i,j)$ respectively, as indicated in Table 2.

(5) Embed the watermark image according to the equation

$$W(i,j) = I_M(i,j) \pm \beta(i,j) W_M(i,j) \tag{3}$$

Table 1 Number of pixels used in calculation of $\sigma(i,j)$

Type	Pixel position in the image	Number of surrounding pixels
A	Corner	3
B	At the edge which is not a corner	5
C	Not at the edge	8

2.3 Analysis

(1) The positive sign in Eq. 4 is used if $W_M(i,j) > I_M'(i,j)$, and negative if $W_M(i,j) < I_M'(i,j)$.

Table 2 Ranges of RSD for different pixel types

RSD	Type	Range of RSD, $\sigma(i,j)$
	A	$0 \leqslant \sigma_T(i,j) \leqslant 104.10$
$\sigma_T(i,j)$	B	$0 \leqslant \sigma_T(i,j) \leqslant 114.04$
	C	$0 \leqslant \sigma_T(i,j) \leqslant 120.21$
	A	$0 \leqslant \sigma_W(i,j) \leqslant 127.50$
$\sigma_W(i,j)$	B	$0 \leqslant \sigma_W(i,j) \leqslant 127.50$
	C	$0 \leqslant \sigma_W(i,j) \leqslant 126.71$

(2) $\beta(i,j) = 0$, if $W_M(i,j) = I_M'(i,j)$, and in this special case $W(i,j) = I_M(i,j)$.

(3) Two pixels in WM produce the same RSD if $I_M'(i,j)$ is equal to the mid-value.

(4) $\sigma_W(i,j) \geqslant \sigma_T(i,j)$.

(5) $0 \leqslant \beta(i,j) < 1$.

(6) $0 \leqslant W(i,j) \leqslant 255$.

(7) As an example, a typical image with its pixel values at the top left corner of the image is given in the matrix IM. Assuming this part is to be covered by a watermark then the matrices below give $I_M'(i,j)$ and $\sigma_T(i,j)$.

$$I_M(1:3,1:3) = \begin{bmatrix} 137 & 136 & 133 \\ 137 & 136 & 137 \\ 138 & 133 & 134 \end{bmatrix}$$

$$I_M'(1:3,1:3) = \begin{bmatrix} 136.3 & 136.00 & 136.33 \\ 136.00 & 135.63 & 134.40 \\ 135.33 & 136.40 & 135.33 \end{bmatrix}$$

$$\sigma_T(1:3,1:3) = \begin{bmatrix} 0.41 & 1.41 & 0.41 \\ 1.53 & 1.76 & 1.24 \\ 1.47 & 1.24 & 1.47 \end{bmatrix}$$

For this particular image Fig. 1 can be used to find the RSD $\sigma_W(1,1)$, $\sigma_W(1,2)$, and $\sigma_W(2,2)$, (examples of type A, B and C pixel respectively), for any watermark image that can be used to embed in positions (1,1), (1,2) and (2,2). The minimum point on each curve is $[I_M'(i,j), \sigma_T(i,j)]$, $W_M(i,j) = I_M'(i,j)$ at this point.

(8) For this algorithm, the RSD of each pixel falls within a range as indicated in Table 2 for different types of pixels.

Conditions for which the minimum and maximum RSD values occur are summarized in Tables 3 and 4 respectively. Parameters in these tables are defined as follows.

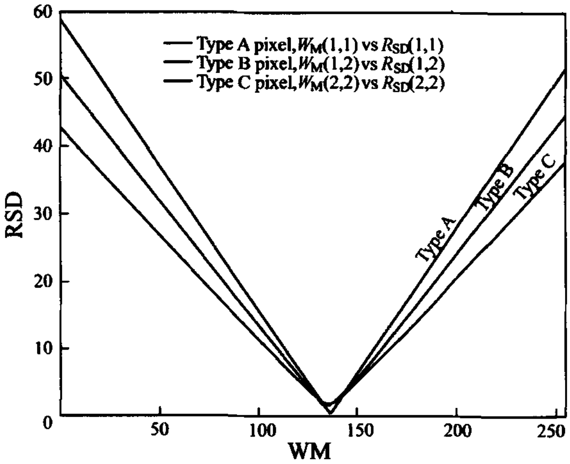

Fig. 1 WM *vs* RSD for pixels of Types A, B and C

$N_{c\ min}$ = number of conditions for which minimum value occurs,

$N_{c\ max}$ = number of conditions for which maximum value occurs,

MPV = mark pixel value,

N_0 = number of surrounding pixels in the original image with value equal to 0,

N_{255} = number of surrounding pixels in the original image with value equal to 255.

(9) From Tables 3 and 4, it can be established that whenever $\sigma_T(i,j) = 0$, $\sigma_W(i,j) < \sigma_{W\ max}$ (*i.e.*, $\sigma_W(i,j) \neq \sigma_{W\ max}$ whenever $\sigma_W(i,j) = 0$) and whenever $\sigma_W(i,j) = \sigma_{W\ max}$, $\sigma_T(i,j) \neq 0$. The probability for $\beta(i,j) = 1$ is zero. This explains the fact that a pixel in W adjust itself according to the difference $I_M'(i,j) - W_M(i,j)$ and add or subtract zero or a fractional part of WM to or from IM making W more closer to both images.

(10) An image whose bottom right corner pixels is given in the matrix below have both $\sigma_{T\ max}$ and $\sigma_{W\ max}$ occurring for Type A, B, and C pixels.

$$I_M(254:256,254:256) = \begin{bmatrix} 255 & 255 & 255 \\ 0 & 255 & 255 \\ 0 & 0 & 0 \end{bmatrix}$$

$$I_M'(254:256,254:256) = \begin{bmatrix} 170 & 204 & 255 \\ 153 & 128 & 153 \\ 85 & 102 & 170 \end{bmatrix}$$

$$\sigma_T(254:256,254:256) = \begin{bmatrix} 104.10 & 93.11 & 0 \\ 114.04 & 120.21 & 114.04 \\ 104.10 & 114.04 & 104.10 \end{bmatrix}$$

Table 3 Conditions for which the minimum RSD occurs

RSD	Type	σ_{min}	$N_{c\ min}$	Pixel value to satisfy a condition for σ_{min} occurrence
$\sigma_T(i,j)$	A	0	1	All surrounding pixels have equal values
	B	0	1	
	C	0	1	
$\sigma_W(i,j)$	A	0	1	Mark pixel value and all the surrounding pixels in the host image have equal values.
	B	0	1	
	C	0	1	

Table 4 Conditions for which the maximum RSD occurs

RSD	Type	σ_{max}	$N_{c\ max}$	Pixel value to satisfy a condition for σ_{max} occurrence
$\sigma_T(i,j)$	A	104.10	2	Condition 1 N_0 = 1 and N_{255} = 2 Condition 2 N_0 = 2 and N_{255} = 1
	B	114.04	2	Condition 1 N_0 = 2 and N_{255} = 3 Condition 2 N_0 = 3 and N_{255} = 2
	C	120.21	1	Condition 1 N_0 = 4 and N_{255} = 4
$\sigma_W(i,j)$	A	127.50	2	Condition 1 MPV = 0 N_0 = 1 and N_{255} = 2 Condition 2 MPV = 255 N_0 = 2 and N_{255} = 1
	B	127.50	2	Condition 1 MPV = 0 N_0 = 2 and N_{255} = 3 Condition 2 MPV = 255 N_0 = 3 and N_{255} = 2
	C	126.71	4	Condition 1 MPV = 0 N_0 = 3 and N_{255} = 5 Condition 2 MPV = 0 N_0 = 4 and N_{255} = 4 Condition 3 MPV = 255 N_0 = 4 and N_{255} = 4 Condition 4 MPV = 255 N_0 = 5 and N_{255} = 3

For this particular image the graphs in Fig. 2 can be used to find the RSD $\sigma_W(256,256)$, $\sigma_W(256,255)$ and $\sigma_W(255,255)$ (examples of Type A, B and C pixel respectively), for any watermark image that can be used to embed in positions (256,256), (256,255) and (255,255). The minimum point on each curve is $[I_M'(i,j), \sigma_T(i,j)]$, $W_M(i,j) = I_M'(i,j)$ at this point.

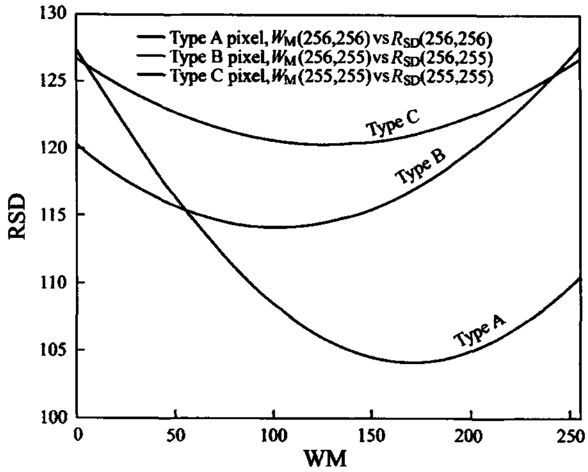

Fig.2 WM *vs* RSD for pixels of Types A, B and C

3 Reconstruction of the Host Image

An important feature of the proposed method is that the original host image IM can be fully restored from the watermarked image W without leaving any perceptible distortion. This is achieved through the following procedure.

(1) The watermark image $W_M(i,j)$ is coded to produce $C_{WM}(i,j)$ and saved.

(2) The matrix $\beta(i,j)$ is saved for a given image.

(3) The values of the pixels in the watermarked image are mostly with fractional part and are rounded off to the nearest integer when saved. The fractional part to be rounded off $W_D(i,j) = W(i,j) - \text{round}[W(i,j)]$, $-0.5 < W_D(i,j) < 0.5$, is also saved.

The key to be applied for the full reconstruction of the host image from the watermarked image is therefore made up of the matrices $C_{MW}(i,j)$, $\beta(i,j)$ and $W_D(i,j)$.

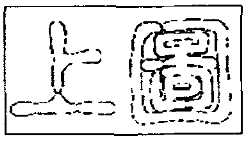

Fig.3 Watermark image 1

Fig.4 Watermark image 2

4 Results

Computation results are shown in Fig.5~8. Fig.3 and 4 are the two watermarks used in the experiment. The added watermarks can be removed to fully restore the original images.

5 Conclusion

A relationship between the pixels in the original image and their corresponding pixels in the watermark image based on the local statistical properties of the pixel in the original image has been established. The established equation is used to embed different watermark images into different host images. Errors in reconstruction of the original image from the watermarked image due to some part of the values of the pixels in the watermarked image being cut off during saving is minimized. The original image is clearly seen under the marked image. A pixel in the mark image adjusts itself due to its position and the values of the surrounding pixels and adds zero or a fractional part to the original image. The original image can be completely reconstructed from the watermarked image without introducing any perceivable distortion. The aim of this work is therefore achieved. This method can be used to embed images for copyright protection since the original image can be fully reconstructed from the watermarked image to make assertion about the image.

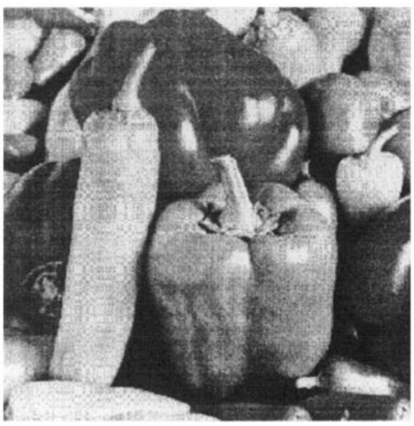

Fig.5 Original image 1

Fig.6 Watermarked image 1

Fig.7 Original image 2

Fig.8 Watermarked image 2

References

[1] Kundur D, Hatzinakos D. Digital watermarking using multiresolution wavelet decomposition [J]. *Proc. IEEE Int. Conf. on Acoustics, Speech and Signal Processing*, Seattle, Washington, 1998, **5**: 2969 - 2972.

[2] Mohanty S P, Ramakrishan K R, Kankanhalli M S. A DCT domain visible watermarking technique for images[J]. *IEEE Int. Conf. on Multimedia and Expo.* (II), 2000: 1029 - 1032.

[3] Chen P M. A visible watermarking mechanism using a statistical approach [J]. *Proceedings of ICSP*, 2000: 910 - 913.

[4] Memom N, Wong P W. Protesting digital media content [J]. *Communication of the ACM*, 1998, **41**(7): 34 - 43.

[5] Glandney H M, Mintzer F, Schiattarella F, *et al*. Digital access to antiquities [J]. *Communication of the ACM*, 1998, **41**(4): 49 - 57.

[6] Radunovic L, Wang S Z. Error reduction for visible watermarking in still images [J]. *Journal of Shanghai University*, 2002, **6**(2): 149 - 153.

[7] Hu Y, Kwong S. Wavelet domain adaptive visible watermarking [J]. *Electronic Letters*, 2001, **37**(20): 1219 - 1220.

(*Executive editor YAO Yue-Yuan*)