LETTER

Contourlet Based Adaptive Watermarking for Color Images

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SUMMARY This paper proposes a contourlet based adaptive watermarking for color images (CAWCI). A color image with RGB space is firstly converted to its YCbCr space equivalent; a luminance (Y) image and two chrominance (Cb and Cr) images are subsequently transformed into contourlet domain respectively; the watermark is embedded into the contourlet coefficients of the largest detail subbands of three images lastly. On the one hand, the embedded watermark is imperceptible because contrast sensitivity function and watermark visual mask are adopted in our CAWCI. On the other hand, the embedded watermark is very robust due to the spread specialty of Laplacian pyramid (LP) in contourlet transform. The corresponding watermarking detection algorithm is proposed to decide whether the watermark is present or not by exploiting the unique transform structure of LP. Experimental results show the validity of CAWCI in terms of both watermarking invisibility and watermarking robustness.

key words: contourlet, image watermarking, information security, wavelet

1. Introduction

Copyright protection of digital images is one of challenging issues imposed in ubiquitous media. Methods of embedding watermark into grayscale images have been researched and developed greatly. However, the research of embedding watermark into color images is insufficient. Since the color image is dominant in the practice, it is valuable to research the watermarking scheme for color images in a further way.

Contrast sensitivity function (CSF) and visual mask are parts of the human visual system (HVS). Visual mask has been adopted in watermarking schemes broadly, and has great contribution for watermarking invisibility [1], [2]. Visual mask used in image watermarking is called watermark visual mask (WVM). CSF is the most important issue in HVS, which concerns the decreasing sensitivity for the higher spatial frequency. However, the research about CSF for image watermarking is few. Furthermore, the correct modeling of the CSF is especially difficult for color images [3].

Conventional watermarking schemes embed watermark into a certain scale subbands in transform domain (either high-frequency (HF) subbands or low-frequency (LF) subbands), thus they can only resist the attack of a particular kind of image processing. Considering a watermarking scheme that embeds watermark into HF subbands, the watermark will be removed easily when the watermarked

image is attacked by the image processing methods which destroy HF of the image, and vice versa. Therefore, most of conventional watermarking schemes are semi-robust in general.

In this paper, we propose a contourlet based adaptive watermarking for color images (CAWCI). Contourlet transform (CT) was proposed by Do and Vetterli in 2002 [4], [5]. In order to satisfy the imperceptibility of the embedded watermark in a color image, we first attempt to combine CSF with visual mask. Furthermore, although the watermark is embedded into the largest detail subbands (the highest-frequency subbands) in the CAWCI, it is likely to be spread out into all subbands when we reconstruct the watermarked color image due to the special transform structure of Laplacian pyramid (LP) [6]. Because LF subbands of the watermarked color image contains watermarking components, the proposed CAWCI is very robust against various HF attacks, such as low-pass filtering, quantization and compression, which will destroy the HF of the color image. On the other hand, some watermarking components can be preserved at HF subbands. Thus, the CAWCI is expected to be also robust to LF attacks, such as gamma correction, histogram equalization, and cropping, which will destroy the LF of the color image. Consequently, the proposed CAWCI is robust to the widely spectral attacks resulting from both the LF image processing and the HF image processing.

The corresponding watermarking detection algorithm is proposed to decide whether the watermark is present or not by exploiting the unique transform structure of LP. It checks the correlation between the watermarked color image and spread watermark in all subbands of contourlet domain. Our detection algorithm is superior to the conventional detection algorithms because it can exploit the correlation of the watermark and all watermarking components in different subbands of the watermarked color image fully.

2. Characteristic Analysis of LP for Watermarking Embedding

Burt and Adelson introduced LP as a multiresolution representation for images in 1983 [6]. Figure 1 shows the LP scheme. Here, H and G are analysis filter and synthesis filter of LP respectively; I is the original image, c and r are the coarse approximation (LF subband) and the difference (HF subband) respectively. The process can be iterated by decomposing the coarse version repeatedly.

By analyzing the scheme of LP, we find that the HF

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Fig. 1 Laplacian pyramid scheme (a) Analysis (b) Synthesis.

subband r is created by subtracting G -filtered LF subband c from original image I , rather than by filtering the original image with a 2-D high-pass filter as wavelet transform (WT) does. In this case, if we change HF coefficients, LF coefficients will be affected likely. We explain it briefly as follows. Here, I' is the modified image; c' and r' are the LF and the HF subband of I' respectively.

$$\begin{aligned} c &= H(I) \quad r = I - G(c) \quad \therefore I = G(c) + r \\ \therefore c &= H(I) = H(G(c) + r) = H(G(c)) + H(r). \end{aligned}$$

The bi-orthogonal filters are normally used for LP filtering. Therefore,

$$H(G(c)) = c \quad H(r) = \mathbf{0}. \quad \therefore r \text{ is orthogonal with } H.$$

It is noticeable that c and $H(r)$ have been down-sampled here, and $\mathbf{0}$ is zero matrix.

When r is changed to r_w randomly, $I' = G(c) + r_w$, which is decomposed by LP again.

$$c' = H(I') = H(G(c) + r_w) = H(G(c)) + H(r_w) = c + H(r_w)$$

Only if r_w is orthogonal with H , i.e. the difference of r_w and r is orthogonal with H , $H(r_w)$ would be zero matrix. But because the change from r to r_w is random, it is hardly possible that r_w is orthogonal with H .

$\therefore H(r_w)$ is likely to not equal to zero matrix, $\therefore c'$ is likely to be different from c .

Because of the characteristic of LP, CT is evidently different from WT. In WT, HF subband is created by filtering the original image with high-pass filter. Therefore, the change of HF coefficients does not affect the LF coefficients. Because WT does not have the spreading effect as LP, the embedded watermark is susceptible to the attacks such as low-pass filtering, quantization and compression that destroy the HF coefficients of the image seriously. In contrast, if the watermark is embedded into the largest detail subbands of CT, it is likely to be spread out into all subbands when we reconstruct the watermarked image. Thus, the watermarking scheme in CT domain may be robust to the widely spectral attacks resulting from both the LF image processing and the HF image processing.

1	2
3	4

Fig. 2 Corresponding sequence numbers of 4 directional subbands.

3. Contourlet Based Adaptive Watermarking for Color Images (CAWCI)

At the beginning of CAWCI, we firstly convert a color image from RGB space to YCbCr space. The reason why the transformation is performed is that an adequate perceptual color space is desired when computing CSF and WVM. Subsequently, the watermark is embedded into three space channels (Y, Cb and Cr) in contourlet domain respectively.

The watermark W to be embedded can be arranged as a set of matrices $W_{s,d}(i, j)$ with size $M \times N$ and pseudo-random binary values $\{-1, 1\}$. The indices s and d indicate the scale and the direction of contourlet subband being embedded by watermark respectively. Embedding watermark into the contourlet subbands of a color image is accomplished according to:

$$C'_{p,s,d}(i, j) = C_{p,s,d}(i, j) + \alpha_p M_{p,s,d}(i, j) W_{s,d}(i, j), \quad (1)$$

where $C_{p,s,d}(i, j)$ and $C'_{p,s,d}(i, j)$ are the original contourlet coefficient and watermarked contourlet coefficient at p channel, resolution scale s and frequency direction d , respectively. Here, $p \in \{Y, Cb, Cr\}$, $s \in \{0, 1, 2, \dots, S\}$, in which S is the coarsest resolution scale, and $d \in \{1, 2, 3, 4\}$, illustrated as Fig. 2. The factor α_p is a strength control parameter of p channel, and $M_{p,s,d}(i, j)$ is a WVM of p channel used to adapt the level of watermark strength and invisibility according to the local characteristics of the image for a given resolution scale s and frequency direction d .

3.1 CSF and WVM

WVM is calculated here by introducing a moderate modifying to the method proposed in [2]. The perceptual sensitivity to noise and brightness variations as well as the presence of significant image features (textures and edges) are taken into consideration in this method. However, WVM in [2] is designed for grayscale images at wavelet domain. In order to achieve WVM for color images at contourlet domain, we introduce CSF to WVM for color images, and modify the method in [2] for contourlet representation. For a given p channel image with resolution scale s and frequency direction d of the contourlet representation, $M_{p,s,d}(i, j)$ is created as:

$$M_{p,s,d}(i, j) = \Theta_{s,d} \text{CSF}_{p,s}(i, j) \Xi_{s,d}(i, j)^{0.2}. \quad (2)$$

Here,

$$\Theta_{s,d} = \begin{cases} 1 & \text{if } d = 1, 3 \\ \sqrt{2} & \text{if } d = 2, 4 \end{cases} \times \begin{cases} 1.00 & \text{if } s = 0 \\ 0.32 & \text{if } s = 1 \\ 0.16 & \text{if } s = 2 \\ 0.10 & \text{if } s = 3 \end{cases}, \quad (3)$$

$$CSF_{p,s} = \begin{cases} 0.555(\Lambda_s + 1.0)^{0.85} & p = Y \\ \frac{[0.908(\Lambda_s + 0.001)]^{0.85}(\Lambda_s^2 + 10)}{10} & p \in \{Cb, Cr\} \end{cases}, \quad (4)$$

and

$$\Xi_{s,d}(i, j) = \sum_{k=0}^{S-s} \frac{1}{16^k} \sum_{x=0}^1 \sum_{y=0}^1 \left[C_{s+k,d} \left(\left\lfloor \frac{i}{2^k} \right\rfloor + x, \left\lfloor \frac{j}{2^k} \right\rfloor + y \right) \right]^2. \quad (5)$$

In (4),

$$\Lambda_s(i, j) = 1.5 + |0.5 - L_s(i, j)|, \quad (6)$$

$$L_s(i, j) = \frac{1}{256} C_s \left(\left\lfloor \frac{i}{2^{3-s}} \right\rfloor, \left\lfloor \frac{j}{2^{3-s}} \right\rfloor \right). \quad (7)$$

Human eye is less sensitive to noise in high resolution subbands and the subbands having orientation of 30° (subband 2) and 60° (subband 4). Both of these effects are considered in $\Theta_{s,d}$. $CSF_{p,s}$ takes the property of channel image and the local brightness of the low-pass version of channel image into account. CSF proposed in [7] for color image is adopted in our scheme. $\Xi_{s,d}$ measures the texture activity in the neighborhood of the given pixel.

3.2 The Watermark Detection Algorithm for CAWCI

The conventional watermark detection algorithms, such as the proposed in [2], only calculate the correlation of the watermark and the watermarked wavelet subbands. Thus, these algorithms cannot work well in our watermarking scheme, where the watermark is likely to be spread out into all subbands. We therefore propose a new watermark detection algorithm for CAWCI. The new watermark detection algorithm is based on the comparison of a correlation value R to a threshold T . The value R is an average measure of the correlation between all contourlet subbands of *spread watermark* and the corresponding contourlet subbands of a given channel image. Here, we define the spread watermark as the contourlet representation with regard to the watermark. It can be constructed by embedding the genuine watermark into the largest detail subbands of a zero-coefficients image (The contourlet coefficients of the zero-coefficients image are all zeros). Contourlet coefficients of the spread watermark can be created by

$$CW_{s,d}(i, j) = \begin{cases} W_{s,d}(i, j) & \text{if } s = 0 \\ 0 & \text{otherwise} \end{cases}. \quad (8)$$

Subsequently, the correlation value R at p channel is calculated by

$$R_p = \frac{2\sqrt{2}}{TOT} \sum_{s=0}^S \sum_{d=1}^4 \sum_{i=1}^M \sum_{j=1}^N C''_{p,s,d}(i, j) CW'_{s,d}(i, j). \quad (9)$$

Here, $C''_{p,s,d}(i, j)$ might be either the original or the attacked version of the watermarked image at p channel. $CW'_{s,d}$ is the contourlet representation of the image reconstructed from

$CW_{s,d}$, and TOT is the number of all contourlet coefficients of the given p channel image. Noticeably, $CW'_{s,d}$ and $CW_{s,d}$ might be different from each other due to the spreading effect in special transforming of LP as analyzed in Sect. 2. In (9), the coefficients of all scales has been exploited since the watermark may propagate into high scales (LF subbands) due to the spreading effect of LP. Note that in contrast, WT does not have the spreading effect and the watermarked wavelet subbands contain all watermark information, so calculating the correlation between the watermark and the attacked image in the highest subbands is sufficient to remove the watermark.

The threshold T at p channel depends on the variance of the contourlet coefficients of the watermarked image at p channel and can be calculated according to

$$T_p = \frac{1}{45TOT} \sum_{s=0}^S \sum_{d=1}^4 \sum_{i=1}^M \sum_{j=1}^N C'_{p,s,d}(i, j)^2. \quad (10)$$

A color image includes three channels: Y, Cb, and Cr. Whether the watermark is present or not in a given color image is decided by

$$\begin{cases} True & \text{if } D \geq 2 \\ False & \text{otherwise} \end{cases}. \quad (11)$$

In which,

$$D = \sum_{p \in \{Y, Cb, Cr\}} d_p, \quad d_p = \begin{cases} 1 & \text{if } R_p > T_p \\ 0 & \text{otherwise} \end{cases}. \quad (12)$$

In our detection algorithm, if the genuine watermark is detected successfully in two channels of the color image, we conclude that the color image is embedded by the genuine watermark; otherwise, the genuine watermark is not in the color image.

4. Experimental Results

To validate the invisibility and the robustness of the CAWCI scheme, we conducted a sequence of tests on different images and apply some attacks to attempt to remove the watermark. The experiments presented in the following are held on 'Lena', 'Peppers', and 'Mandrill' color images with the size 512×512 .

In our experiments, the three channel images (Y, Cb and Cr) are transformed into contourlet representation with $S=3$ respectively, and the watermark is embedded into four largest detail subbands by adjusting their strength based on the calculated WVM. A high degree of watermark invisibility with PSNR values around 43 dB for three test color images can be achieved in our scheme.

For the evaluation of the performance of the proposed watermark detection algorithm, we collect its responses to 1000 different watermarks including the genuine (embedded) one. The experimental results of one correct detection (for the genuine watermark) and 999 false detections (for all other fake watermarks) demonstrate the high effectiveness

Table 1 Experimental results of watermarking embedding and detection for CAWCI.

Image	Lena	Peppers	Mandrill
Strength factor α (Y/Cb/Cr)	0.04/0.04/ 0.04	0.04/0.01/ 0.01	0.04/0.01/ 0.01
PSNR (Y/Cb/Cr)	44.67/ 44.34/ 46.22	43.89/44.83/ 46.56	42.11/ 43.91/ 45.25
Threshold T (Y/Cb/Cr)	2.54/0.23/ 0.35	3.43/1.35/ 1.38	8.08/2.82/ 2.31
R (Y/Cb/Cr)	8.55/8.39/ 6.94	9.15/7.51/ 6.05	13.79/7.12/ 6.44
R' (Y/Cb/Cr)	0.28/0.11/ 0.22	0.33/0.11/ 0.13	0.42/0.07/ 0.15
D	3	3	3

Table 2 Detecting results when the watermarked color image 'Lena' is attacked by various processing methods.

Attacking Method	Threshold T (Y/Cb/Cr)	R (Y/Cb/Cr)	R' (Y/Cb/Cr)	D
Median Filtering	0.54/0.28/ 0.43	0.80/0.59/ 0.85	0.36/0.14/ 0.19	3
JPEG	2.19/0.07/ 0.21	3.28/0.11/ 0.23	0.30/0.06/ 0.18	3
Gaussian Noise	3.26/4.43/ 2.83	7.83/8.87/ 6.55	1.47/0.81/ 0.88	3
Rotation	1.22/0.16/ 0.40	0.93/0.55/ 0.82	0.13/0.03/ 0.01	2

of our detection algorithm to recognize the genuine watermark. Table 1 shows the experimental results of watermarking detection. Here, R is the detecting response to the embedded one and R' is the highest detecting response to 999 fake watermarks.

To assess the robustness of our watermarking scheme, median filtering with 5×5 window size, JPEG compression with the quality factor 50, Gaussian noise with zero mean-value and 0.01 variance, and rotation with 0.5° were applied on the watermarked images. In all cases, the genuine watermark can be detected successfully, consequently demonstrating an excellent robustness of our watermark-

ing scheme and a high validity of our detection algorithm. Table 2 illustrates the experimental results of 'Lena'.

5. Conclusion

We have proposed a new watermarking scheme, namely CAWCI, which offers both invisibility and robustness. Correspondingly, a new watermark detection algorithm has been proposed for CAWCI. Compare to the traditional watermarking schemes based on wavelet for color images, the computational complexity of our watermarking scheme has not been increased because WT is replaced by CT and CSF is applied additionally in our watermarking scheme merely. Experimental results have shown that the proposed scheme is completely robust against common attacks.

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