MVA2015 IAPR International Conference on Machine Vision Applications, May 18-22, 2015, Tokyo, JAPAN

Digital Image Watermarking on Illumination Component

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Abstract

This paper proposes a digital image watermarking method in homomorphic domain. In the proposed method, a homomorphic filter is applied to the host color image to extract a low variational illumination component. This component is used to embed a binary watermark image with the same size as host image. The watermark extraction is achieved by using an original illumination component prediction technique based on linear combination of watermarked component values around the embedded one. The predicted component is subtracted from the watermarked component to obtain the extracted watermark. The performance of the proposed method in terms of average NC is evaluated and compared with the previous work. Its robustness against image processing based attacks at various strengths is also compared.

1. Introduction

The world of digital communication is almost limitless. Transmitting digital media, i.e. image, video, and audio is merely a simple click without any quality loss, so that it is not difficult to make an illegal copy and distribute it to the global network. Image watermarking is one of the methods used to verify the real ownership of an image by embedding secret information called "watermark" into that image. With a decent image watermarking, the quality of watermarked image should not be perceptible to the observer, while the embedded watermark should be robust against all possible noises and attacks.

Basically, image watermarking can be classified into two main groups based on its working domain, i.e. spatial and frequency domains. In the frequency domain, the watermark is embedded by modifying some coefficients obtained from the transformed image pixels e.g. the discrete wavelet transform (DWT) or the discrete cosine transform (DCT), while in the spatial domain, the watermark embedding is performed by directly modifying the host image pixels. In 1998, M. Kutter *et al.* [1] proposed an image watermarking method based on amplitude modulation. Their method was proved to be robust against various types of attacks including JPEG compression standard. The method embedded a watermark bit into an image pixel by modifying the blue component of that pixel using either additive or subtractive depending on the watermark bit, and proportional to the luminance of the embedding pixel. The watermark extraction was blindly achieved by using a prediction technique based on a linear combination of pixel values in a cross-shape neighborhood around the embedded pixels. The predicted original pixel value was then subtracted from the watermarked one to extract the watermark bit. To improve its performance, T. Amornraksa *et al.* [2] proposed some techniques to enhance the accuracy of the extracted watermark, i.e. by rearranging the pattern of watermark bits around the embedding pixels, adjusting the strength of embedding watermark in accordance with the nearby luminance, and using a new linear combination of surrounding watermarked pixel values around the embedded pixels. The authors also demonstrated how to embed a watermark image (logo) with the same size as the host color image. In 2012, K. Thongkor *et al.* [3] proposed an image watermarking for camera-captured image containing partial shadowed area, where the concept of watermarking method in [2] was extended to cover problems in a practical watermarking application, i.e. by cooperating the image registration technique based on projective transformation in order to diminish both RST and perspective distortions caused by the printing and camera-capturing processes. In 2014, S. Tachapetpiboon *et al.* [4] proposed an image watermarking in HSV model, where the S color component was used to carry the watermark, while H. A. Abdalah *et al.* [5] presented a homomorphic image watermarking method based on the Singular Value Decomposition algorithm, where the luminance component in *YCrCb* color model was used to carry the watermark. However, the above methods [1-3] still has a weakness when applied to some particular type of images containing high variation of image pixel values, resulting in a low accurate extracted watermark, while the watermark embedding in [4-5] was performed on different components having different properties and characteristics.

In this paper, we observe that a low variational image component within the blue component can be used to carry the watermark in order to increase the accuracy of extracted watermark. We thus propose a new image watermarking method in homomorphic domain for color images. In the proposed method, the homomorphic filter is applied to the blue component of the host image pixels in order to extract a low variational illumination component, and used it to embed a watermark. The similar watermark extraction concept on blue component as in [2], is implemented on the watermarked illumination component in order to extract the embedded watermark.

2. Obtaining Illumination Component from Homomorphic Filter

In digital image process, homomorphic filter is well known as a way for decreasing image dynamic range and increasing image contrast [6]. Accordingly, an image is assumed to consist of two multiplicative components: illumination and reflectance. Illumination component L is the amount of light falling on the image while the reflectance component R is the amount of light reflected by the image, i.e $I(i,j) = L(i,j)R(i,j)$. Illumination component is normally characterized by slow spatial variations, while reflectance component tends to vary abruptly, particularly at the junctions of dissimilar objects [7]. Most of the image details lie in the reflectance component, and the illumination component is approximately constant [8]. To separate the illumination component from the image effectively, the natural logarithm is first performed on the image pixel values in order to convert the multiplication relationship between the two components to the addition one, i.e. $I(i,j) = L(i,j)R(i,j)$, and applying a low pass filter to the result. To reconstruct the orginal image, we perform the natural exponential function on the combination of both illumination and reflectance components. The block diagram of the homomorphic filtering process is shown in Fig. 1. Note that the basis of homomorphic filter is working with the logarithm of the image, rather than with the image directly, so that the variation of the illumination component values is very low. For convenience, from now on the natural logarithm of illumination component, $ln(L'(i,j))$, will be called "illumination component" for short. It was shown in [4] that the variation of image component affected the watermark extraction performance, and low variation in embedding component values helped improve the accuracy of extracted watrmark. The illumination component in the homomorphic domain of the blue component is therefore used to carry the watermark. In this paper, a standard Gaussian high-pass filter, as shown in (1), in MATLAB is used.

$$H(i,j) = 1 - e^{\frac{-(i^2+j^2)}{2\sigma^2}}, \qquad (1)$$

where i and j is the distance from the origin in the horizontal and vertical axis, respectively. σ is the standard deviation of the zero mean Gaussian distribution. The illumination component L is obtained by substracting $ln(R(i,j))$ from $ln(I(i,j))$.

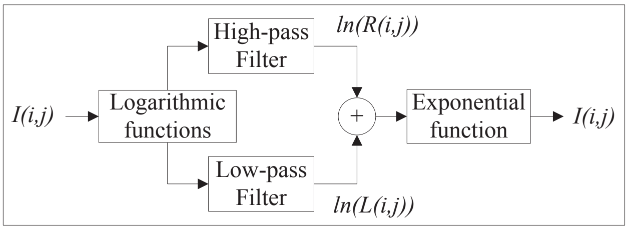

Fig. 1. Block diagram of homomorphic filtering process

3. Proposed Watermarking Method

A watermark image I_w is created using only two colors: black (0) and white (1). The watermark bits are first permuted by using Gaussian distribution to disperse bits 0s and 1s, and the result is XORed with a pseudo-random bit stream generated from a key-based bits generator. Finally, bits 0s are converted into -1, so that the watermark to be embedded become as $w(i,j) \in \{-1,1\}$. The watermark embedding is performed by modifying the illumination component $ln(L(i,j))$ of the host image $I(i,j)$ in a line scan fashion, left to right and top to bottom. The modification of $ln(L'(i,j))$ are modified in accordance with $w(i,j)$ and watermark strength s. The watermarked component $ln(L'(i,j))$ can be represented by

$$ln(L'(i,j)) = ln(L(i,j)) + w(i,j) \cdot s. \qquad (2)$$

$ln(L'(i,j))$ is next combined with $ln(R(i,j))$, followed by the exponential function to obtain the watermarked image, $I'(i,j)$. Block diagram of the watermark embedding process is illustrated in Fig. 2. The watermark extraction is directly performed on the watermarked illumination component, $ln(L'(i,j))$. The prediction of $ln(L(i,j))$, $ln(L''(i,j))$, can be estimated from the surrounding neighborhood of $ln(L'(i,j))$, as given by

$$ln(L''(i,j)) = \left[\frac{1}{8} \left(\sum_{m=-1}^{1} \sum_{n=-1}^{1} ln(L'(i+m,j+n)) - ln(L'(m\_max,n\_max)) \right) \right], \qquad (3)$$

where $ln(L'(m\_max,n\_max))$ is a neighboring component around (i,j) that most differs from $ln(L'(i,j))$. The extracted watermark $w'(i,j)$ is then obtained by substracting $ln(L''(i,j))$ from $ln(L'(i,j))$. Since $w'(i,j)$ can be either positive or negative, its sign is used to estimate the value of $w(i,j)$. That is, if $w'(i,j)$ is positive (or negative), $w'(i,j)$ is estimated as 1 (or -1, respectively). Note that the magnitude of $w'(i,j)$ reflects a confident level of estimating $w(i,j)$. Finally, the bits -1s of $w'(i,j)$ is converted into 0, and the result is XORed with the same bit stream, as used in the embedding process and then passed to invert permutation to obtain the extracted watermark image $I'_w(i,j) \in \{0,1\}$. Block diagram of the watermark extraction process is illustrated in Fig. 3.

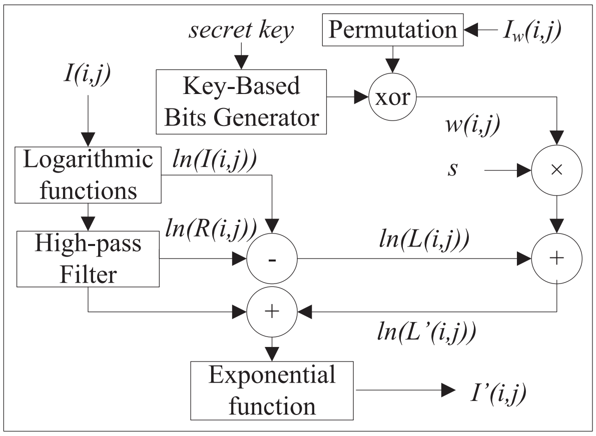

Fig. 2. Block diagram of watermark embedding process

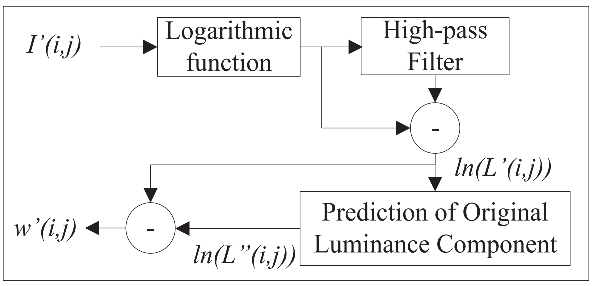

Fig. 3. Block diagram of watermark extraction process

4. Experimental Setting and Results

Nine standard 256×256 pixels color images having various characteristics were used as original images, i.e. '*house*', '*lena*', '*baboon*', '*splash*', '*girl*', '*barbara*', '*fruits*', '*airplane*' and '*couple*'. A 256×256 pixels binary image containing a logo '*KMUTT*' was used as watermark. A human visual system based quality measure called weight Peak Signal-to-Noise Ratio (*wPSNR*) was used for evaluating the quality of watermarked image. *wPSNR* is a variation of PSNR that uses weights for perceptually different image areas based on the visibility of noise in flat image areas which is higher than that in textures and edges. The calculation of *wPSNR* for a color image is defined as

$$wPSNR\,(\text{dB}) = 20\log\frac{255\sqrt{3MN}}{\sqrt{\sum_{k=1}^{3}\sum_{i=1}^{M}\sum_{j=1}^{N}[NVF(I'(k,i,j) - I(k,i,j))]^2}}, \quad (4)$$

where *NVF* is the noise visibility function which characterizes the local texture of an image and varies between 0 and 1, where 1 is for flat areas and 0 is for highly textured areas. *M* and *N* are the numbers of row and column in the images, respectively. A popular similarity measurement called Normalized Correlation (*NC*) was used for evaluating the accuracy of extracted watermark. The calculation of *NC* is given by (5). Note that the maximum value of *NC* is 1. A higher *NC* value indicates a more accurate extracted watermark.

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} I_w(i,j) I'_w(i,j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} I_w(i,j)^2}\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} I'_w(i,j)^2}}, \quad (5)$$

We first compared the variation of the embedding components in [1-3] to the one in the proposed method. We divided the embedding components, i.e. the blue component in the previous methods and the illumination component in the proposed method, into blocks of 3×3, and calculate the variance of 9 components within each block. The normalised variance obtained from the test image '*barbara*' at each 3×3 block, in a successive order, from left to right and top to bottom, from the first 200 blocks is shown in Fig. 4. From the result, the normalised variances of the blue and illumination components for the whole image are 0.051 and 0.028, on average, respectively.

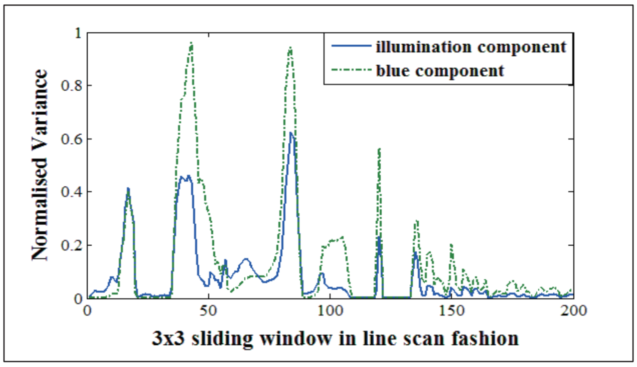

Fig. 4. Normalized variance of 3×3 blocks in (a) blue component and (b) illumination component

We next compared the accuracy of extracted watermark at equivalent quality of watermarked image between the proposed method and the previous one in [3]. The results in terms of average *NC* at different *wPSNR* values between the two methods were measured and compared, see Fig. 5. The original watermark image and its extracted versions obtained from the two methods at *wPSNR* of 30±0.01 dB are shown in Fig. 6.

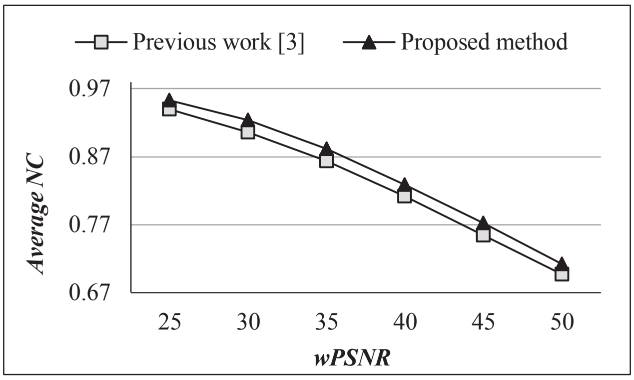

Fig. 5. Performance comparison between the proposed method and the method in [3] at different wPSNR values

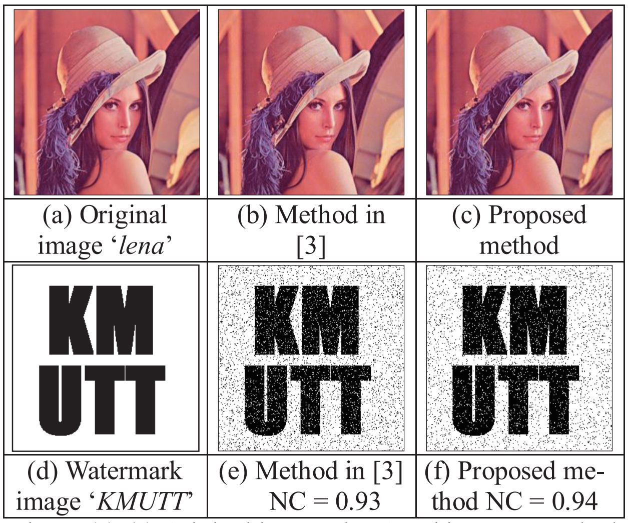

Fig. 6. (a)-(c) Original image '*lena*' and its watermarked versions (d)-(f) watermark image and its extracted versions

Clearly, from the figure, the proposed method obtained a higher accurate watermark at all comparing image qualities. Note that the accuracies of the predictions of original *ln(L(i,j))* in the proposed method and original blue component in [3] in terms of average *NC* were 0.999 and 0.994, respectively. Finally, we evaluated the robustness of the embedded watermark by applying different attacks at various strengths to I', obtained from the two methods at *wPSNR* of 30±0.01 dB. Five types of attacks were used, namely, JPEG compression standard at image qualities from 100 to 50%, brightness enhancement from 15% to 100%, contrast adjustment by scaling factors from 1 to 2, image blurring from 1 to 10 pixels, and image sharpening by factors from 0.2 to 1.2, see Fig. 7-11, respectively.

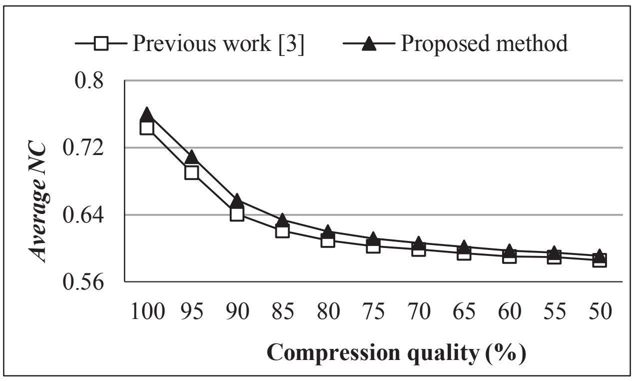

Fig. 7. JPEG compression standard

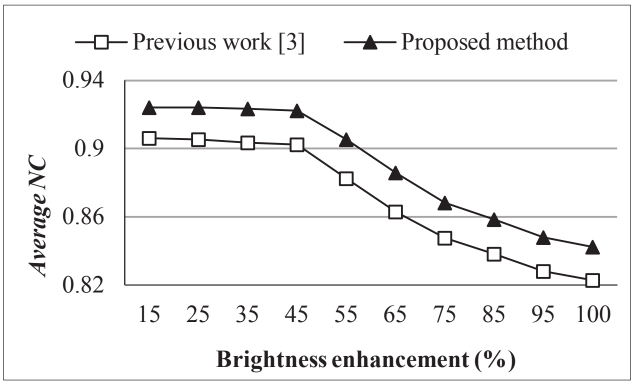

Fig. 8. Brightness enhancement

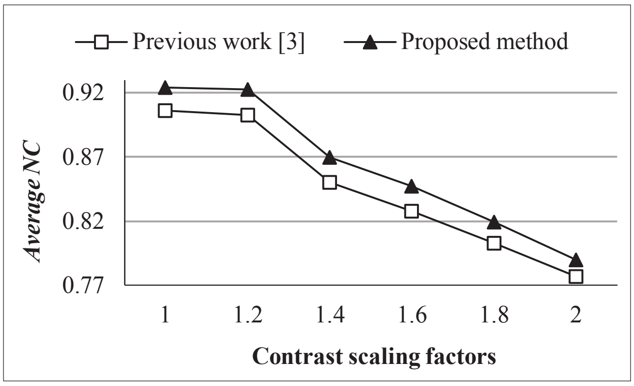

Fig. 9. Contrast adjustment

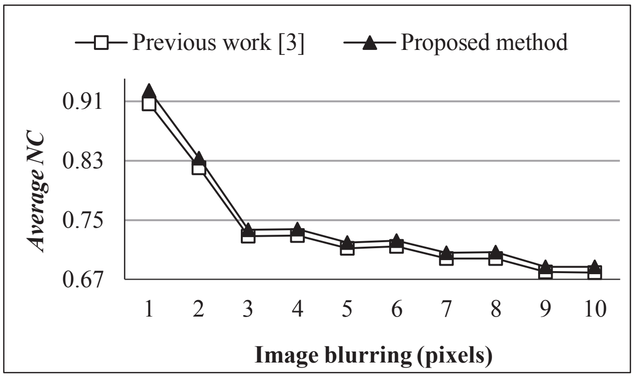

Fig. 10. Image blurring

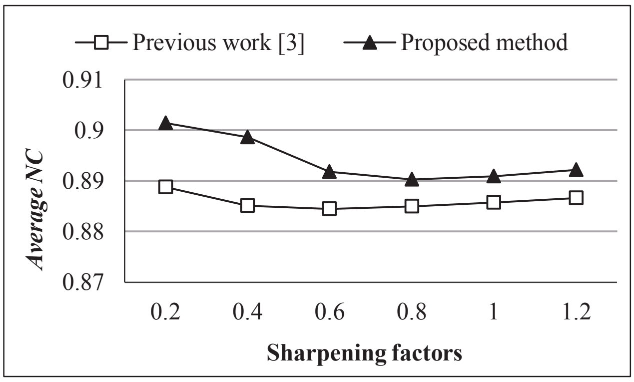

Fig. 11. Image sharpening

It is obvious that the proposed method was, on average, more robust than the previous method. Fig. 12 shows some examples from the two methods after image compression by JPEG at 95% quality, image blurring at 4 pixels, and image sharpening at factor of 0.04 respectively. Note that the watermarked image quality from the two methods was controlled to achieve the *wPSNR* of 30±0.01 dB as well. From the result, the visual quality of the extracted watermarks from the proposed method was slightly lighter with the naked eye, although the average *NC* obtained from the new method was higher.

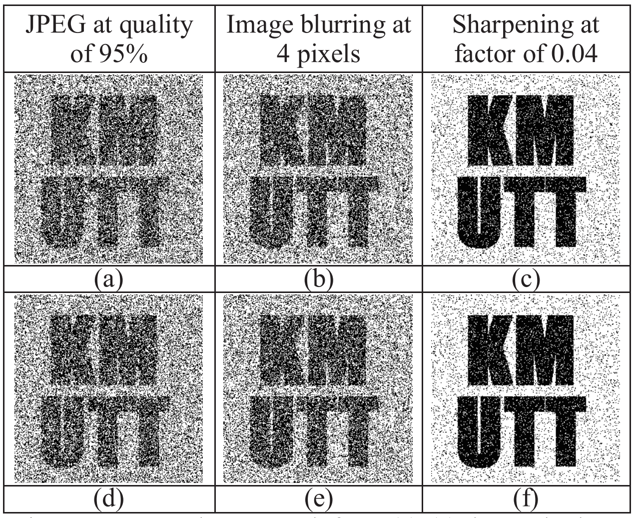

Fig. 12. Extracted watermark from (a)-(c) the method [3] and (d)-(f) the proposed method

5. Conclusion

The image watermarking method based on the modification of illumination component in the homomorphic domain was shown to achieve a better performance in terms of *NC* at equivalent *wPSNR* than the previous method [3]. The proposed method also achieve a higher accurate extracted watermark under various attacks.

References

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