μ-Law Based Watermarking for HDR Image Robust to Tone Mapping

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***Abstract*— High Dynamic Range (HDR) images have been widely applied in daily applications. However, HDR image is special format, which need to pre-process known as tone mapping operators for display. Since the visual quality of HDR images are very sensitive to luminance value variations, conventional watermarking methods for low dynamic range (LDR) images are not suitable and may even cause catastrophic visible distortion. Currently, few methods for HDR image watermarking are discussed. In this paper, we propose a watermarking scheme for HDR image. Both of the subjective and objective qualities of watermarked image are improved. What's more, it also shows higher robustness against tone mapping operations.**

I. INTRODUCTION

Protection of copyright attracts lot of attention in recent years, because digital contents become easily accessed on computer networks. To solve this problem, the so-called digital watermarking technology has been developed, which is the embedded information insensible to human visual system. In general, digital image watermarking technology must follow two properties. First, the perceptual quality of the original image should not be degraded by the embedded watermark. Moreover, the watermark is robust to image manipulations, such as lossy compression, cropping, collusion attacks, etc.

By adapting lights in any viewing condition, a wider range of radiance can be perceived by the human visual system than by commercially available sensors. In the last decade, to capture the high dynamic range of natural scene brightness, techniques have been proposed based on the multi-exposure image principle [4]. A method for merging multiple photographs shot with different exposures has been proposed by Mann et al. [4], in which, high dynamic ranges have been realized. Devebec et al. [4] has also proposed a method to create High Dynamic Range (HDR) Images (e.g. contrast ratio of 10^{10}: 1) and applied to high quality image based lighting.

Big mount of applications have been inspired by HDR imaging, such as high quality CG rendering, in-vehicle sensors, camera surveillance, digital negative developments, etc. Since the dynamic range of HDR images may be far beyond the one of display devices, it is difficult to display directly. "Tone mapping operations" have been proposed, in which the dynamic ranges of the HDR images are reduced to displayable ranges [4]-[7]. These operations aim at reducing the high dynamic range without loss of detail.

Nevertheless, to our knowledge, little contribution has been made on HDR image watermarking. Since the HDR image is very sensitive to luminance value variations, conventional watermarking methods for low dynamic range images are not suitable and may even cause catastrophic visible distortion. In this paper, a digital watermarking scheme targeting HDR images is proposed, and the HDR image is converted to the LDR image part and the residual part based on μ-law. The watermark is embedded in the LDR image part of the HDR image by conventional watermarking method. Due to an average of 15dB is increased in PSNR, which can be achieved by the proposed algorithm for the watermarked images with corresponding improvement in subjective quality, it is quite different from the way of conventional watermarking method for LDR image apply to the HDR image directly. It also shows higher robustness against tone mapping operations.

The paper begins with description of previous research in Section 2. The proposed method is given in Section 3. Experimental results are shown in Section 4 followed by conclusions in Section 5.

II. CONVENTIONAL METHOD

Many methods for watermarking have been also proposed in the last several years. For example, the Discrete Wavelet Transform (DWT) based method [1] [2], and the DCT based method [3]. But these methods are only applied to the Low Dynamic Range Image (LDRI). Few researches for HDR image watermarking have been studied. Thus, to propose the watermarking for HDR image, the DWT based method for watermarking [1] is used directly as a pre-screening process. That is the watermark is directly added to the wavelet coefficients of LH and HL components of HDR image. And the watermarked HDR image is reconstructed by IDWT. But the HDR image is very sensitive to luminance value variations, the conventional method is applied to HDR image directly may cause catastrophic visible distortion.

III. THE PROPOSED METHOD

In this section, we proposed a digital watermarking scheme targeting HDR images. To make the HDR watermarking robust to tone mapping, a modify scheme is proposed. The procedure is depicted in Fig.1, firstly, the HDR image is converted to LDR image by a user-selected tone mapping operator. In this paper, µ-Law based tone mapping model is used. Then the HDR image is divided by the LDR image, that is, the HDR image is converted to the LDR image and the residual *R*. The watermark is added to the LDR image. At last the watermarked LDR image (*LDRI'*) is multiplied by the residual *R* to reconstruct the watermarked HDR image (*HDRI'*). Details algorithm will be introduced as following.

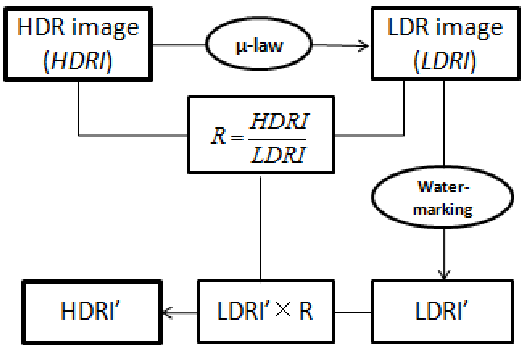


Fig.1. The proposed method

A. µ-Law based tone mapping model

We introduce the following tone mapping model, which is similar to µ-Law encoding [8]

$$f(x) = s\frac{\ln\{1+(\mu/s)x\}}{\ln(1+\mu)} \tag{1}$$

where *s* is a scaling parameter and µ controls the "depth" of the logarithm function.

To design the model, at first, a tone mapping operator is designed, which will be actually used after watermarking. Then the LDRI is created by the operator. We find the parameters *s* and µ by minimizing the cost function:

$$\min_{s,\mu} E = \sum_i \{f(H_i) - L_i\}^2 \tag{2}$$

where *H* and *L* are the HDRI and its tone-mapped LDRI, respectively, and the suffix *i* is a pixel index. Here, the optimization method of the interior trust region approach for the reflective Newton method [9] is used.

After this optimized model the HDR image can be tone-mapped to its LDR image.

B. Watermark embedding scheme

The watermark is added to the LDR image. At the beginning, LDR image is converted to the YUV color space and the intensity *Y* of the image is transformed by N-level wavelet transform. Thereby *LHn*, *HLn*, *HHn* and *LLn* are obtained. Here, *LHn* and *HLn* components are only used to embed the watermark $x \in X$, because we consider the quality of the image and the robustness of the watermark. Here *X* stands for a set of watermark, and the elements x_i ($i = 1,2,\ldots,M$) of x are the random noise sequence that has a normal distribution of zero mean and unit variance. We embed the watermark x_i by

$$W_i' = W_i + \alpha|W_i|x_i \qquad i = 1,2,\ldots,M \tag{3}$$

where W_i is wavelet coefficient of the original image; W_i' denotes the wavelet coefficient of the watermarked image; α is a scaling parameter.

After embedding the watermark, the output image should be transformed by inverse wavelet transform. The watermarked LDR image (*LDRI'*) can be obtained. At last, the watermarked LDR image (*LDRI'*) is multiplied by the residual *R* to reconstruct the watermarked HDR image (*HDRI'*).

IV. Experimental Results

A. Watermark detection

In this paper, the original image is not used for detecting the embedded watermark. Instead, we only judge whether the watermark is embedded in the image using the threshold. The detection method is proposed by [2]. Firstly, the correlation *z* between the wavelet coefficients W' of the watermarked image and a possibly different watermark *Y* is computed as

$$z = \frac{1}{M}\sum_{i=1}^{M} W_i' y_i \tag{4}$$

where M represents the number of all the DWT coefficients, i.e., the length of the watermark sequence. To detect the watermark, a threshold S_x is applied for comparison.

To determine the threshold S_x, the variance of *z* is considered.

$$\sigma_z^2 = \frac{\sigma_{y_i}^2}{M^2}\sum_{i=1}^{M} E\left[(W_i')^2\right] \tag{5}$$

Using the error function the threshold satisfies

$$P_f \le \frac{1}{2}\,erfc\left(\frac{S_z}{\sqrt{2\sigma_z^2}}\right) \tag{6}$$

thus S_x is determined.

For example, selecting $P_f \le 10^{-8}$, S_z is determined by

$$S_z = 3.97\sqrt{2\sigma_z^2} \tag{7}$$

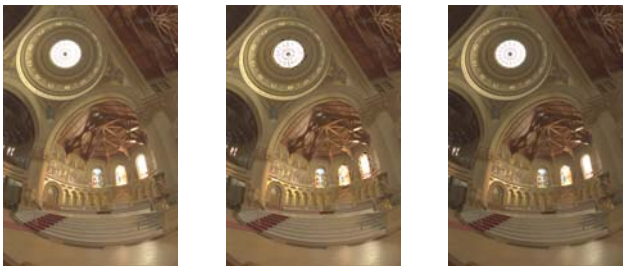
At last to detect the watermark, Eq.(7) is used to compare with *z*. If $z >> S_z$, one can safely declare the watermark detected.

B. Experimental results

In the experiments, 3-level DWT is applied and the parameter in embedding watermark α is set to 0.4. The watermark is only embedded at LHL, LLH, HL and LH sub bands. We compare our results with the conventional method [1].

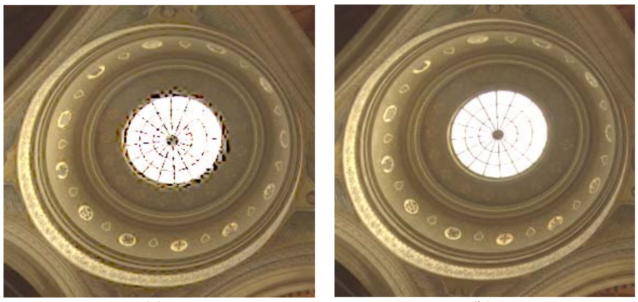
Firstly, the original HDR image and its watermarked version of the conventional method are shown in Fig.2(a) and Fig.2(b), while the result of the proposed method is shown in Fig.2(c), It should be mentioned that Fig.2 is gamma encoded for proper display. The values of PSNR of the conventional and proposed images are PSNR1 = 16.7514 and PSNR2 = 70.7094, respectively. It can be found that the conventional method of the embedded watermark degrade the perceptual quality of the original image. The noise of the watermarked image can be visible at light part. And one part of the images is expanded showing as Fig.3. Then the results are shown for other images in Table Ⅰ. When the conventional method is applied to the HDR images directly, it could be found large error occurs. However, the proposed method preserves image quality well. From the values of PSNR and these images, the proposed method out performs the conventional one. Then we show the PSNR of LDR image tone mapped form the watermarked HDR image as TableⅡ. We can conclude that the qualities of the LDR images are also improved. And we can find the watermarks in both of two watermarked images from proposed method are invisible in Fig.8.

To analyze its robustness against the tone mapping operators and lossy compression, four tone mapping operators Reinhard et.al.'s operator[4] are tested, which are same as one used in embedding side, the matlab function tonemap() in Image Processing Toolbox, Gradient based method[6], and iCam operator[7], all of them are local operators. To evaluate the validity of the proposed algorithm, we prepare a thousand patterns of the watermarks, and we embed the 200th watermark to images and evaluate the detection capability. Fig.4(b) shows the detection capability of the proposed method under attacks, where the threshold. The x-axis shows the indices of the 1000 watermarks and the horizontal line in the figure denotes the threshold *Sz*. Only the 200th watermark far exceeds the threshold, while the other watermarks are below it. It means that the detection can be employed safely. In Fig.4-Fig.7, we show the results of the four attacks of tone mapping operators. It can be seen that only 200th watermark exceeds the threshold and we safely detect the watermark regardless of the attacks of the tone mapping.



(a) (b) (c)

Fig.2. Subjective quality comparison for: (a) the original input image (memorial.hdr); (b) watermarked image generated by [1]; (c) watermarked image generated by the proposed method.



(a) (b)

Fig.3. Subjective quality comparison for: (a) Enlarged portion of Fig.2(b); (b) Enlarge portion of Fig.2(c)

TABLE Ⅰ

Comparison in PSNR of HDRI (dB)

Image	[1]	Proposed method
memorial.hdr	16.7514	70.7094
Desk_oBA2.hdr	13.0949	53.0356
AtriumNight_oA9D.hdr	25.0912	51.1529
bigFogMap_oDAA.hdr	32.0551	72.6204
dani_synagogue_o367.hdr	24.8796	55.4765

TABLE Ⅱ

Comparison in PSNR of LDRI (dB)

Image	[1]	Proposed method
memorial	28.0514	52.3923
Desk_oBA2	24.7643	46.7113
AtriumNight_oA9D	32.4685	46.7865
bigFogMap_oDAA	46.4029	54.0374
dani_synagogue_o367	41.5604	55.7619

V. CONCLUSIONS

In this paper, we propose a method for HDR watermarking based μ-law. The HDR image is converted to the LDR image part and the residual part. The watermark is embedded in the LDR image part. Compared with the conventional method, watermarking in the proposed method is invisible, both of the PSNR of HDR image and LDR image are increased; and robustness against the attack such as tone mapping.

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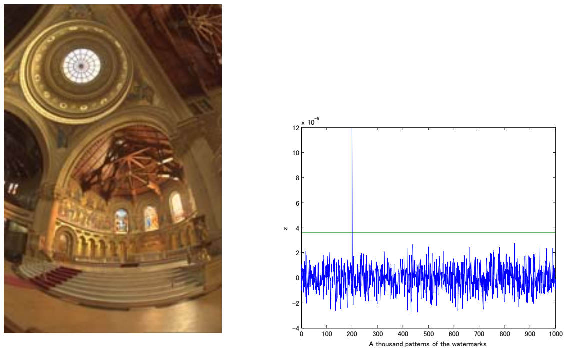
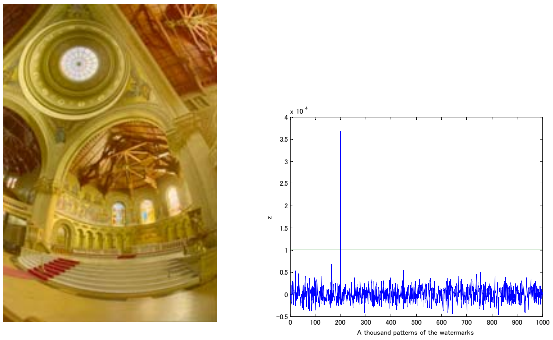


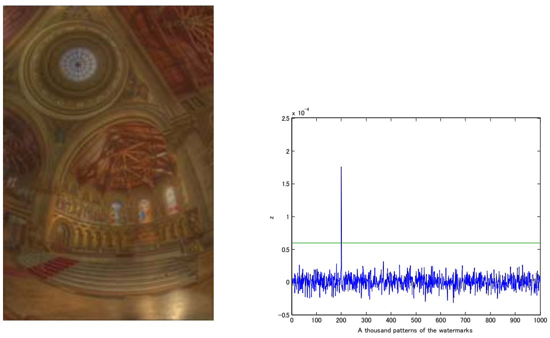
(a) LDR image (b) threshold vs. variance

Fig.4. LDR tone mapped by Reinhard et al.'s method [3]



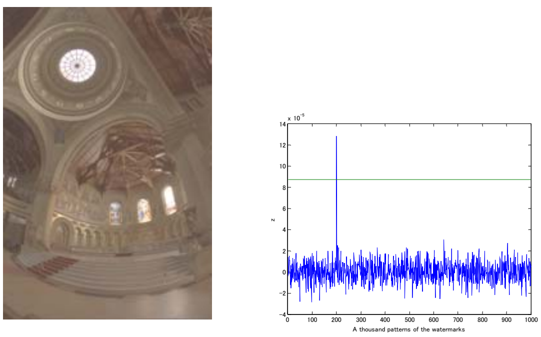
(a) LDR image (b) threshold vs. variance

Fig.5. LDR tone mapped by a tone mapping function in MATLAB



(a) LDR image (b) threshold vs. variance

Fig.6. LDR tone mapped by Gradient based method [5]



(a) LDR image (b) threshold vs. variance

Fig.7. LDR tone mapped by iCam's tone mapping [6]

(a) (b)

(c) (d)

Fig.8. Subjective quality of proposed method: (a) (b) the original input images (c) (d) watermarked image generated by proposed method.

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