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HDR IMAGE GENERATION FROM LDR IMAGE WITH HIGHLIGHT REMOVAL

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ABSTRACT

The emergency of High Dynamic Range (HDR) display device impels the study of generating HDR image from Low Dynamic Range (LDR) image. Most existing generation methods apply complicated handing to highlight areas in image, which perplexes the algorithm and introduces the probability of generating artifacts. In this paper, we investigate a separated scheme: instead of sophisticated treatment to the highlight areas during expanding, the processing to the highlight areas is separated from the dynamic range expansion, which facilitates the framework and reduces the artifacts. The image quality metric shows that the separated scheme reveals more details with little artifacts compared to the algorithms considered in the comparison; the experimental results prove that the proposed method allow to obtain high quality HDR image.

***Index Terms*—** High Dynamic Range (HDR), Low Dynamic Range (LDR), image expansion, highlight removal, Principle Component Analysis (PCA)

1. INTRODUCTION

High Dynamic Range (HDR) image greatly extends the dynamic range of the legacy Low Dynamic Range (LDR) image [1][2]. Moreover, HDR display device is capable of providing a rich visual experience, video or image displayed on it looks more approximate to real world scenes. Along with the development of the HDR display device, how to acquire HDR image has attracted great attention [3][4]. Among the acquiring methods, the generation of HDR contents from LDR contents has been a research focus [5]. The most expedite scheme is proposed by Akyuz *et al*. [6], which is a linear expansion method. Because there are always highlight areas in image in practice, researchers have presented algorithms to extend this kind of images [7][8][9][10]. Meylan *et al*. [7] indicated a piece-wise linear expansion function, which expands the highlight areas more than other areas. Banterle *et al.* [8] proposed a framework, which first expands LDR images to middle dynamic range by an iTMO (inverse Tone Mapping Operator), then computes an expand-map to reconstruct the lost luminance profiles in high luminance areas and attenuate the quantization or compression artifacts that can be enhanced during expansion. With a similar fashion, Rempel *et al*. [9] extended LDR image to middle dynamic range before expanding by a brightness enhancement-map combined with an edge-stopping function. Masia *et al*. [10] presented an expansion method based on γ transformation, focusing on images with large highlight areas.

Most existing image expansion methods make a general assumption that highly saturated pixels need to be expanded much more than the rest [10]. As a result, bright image areas representing features like highlights, or the sun in the sky, are largely boosted, thus results in contouring artifacts for bright object sometimes; furthermore, most algorithms expand the highlight areas using sophisticated fashion that is different from the method conducted on other areas during expanding, which makes image worse than before expanding [10]. On the other hand, highlights make image processing difficult, considering the commonplace of highlights in images, for obtaining pleasant HDR image, it is necessary to process the highlights before expanding step. To solve these problems, we present a novel method which avoids special treatment to highlight in the expansion procedure and removes the highlights in the result images.

In this paper, a new expansion scheme is proposed for generating HDR image from LDR image. In contrast with the existing methods, we focus on the expansion of the highlight pixels, by pre-processing of the highlight to eliminating their influence before expanding and avoiding the formation of the artifacts. Thus, the most important novelty of this algorithm is the fashion that expands the highlight areas, unlike the existing methods, the proposed scheme does not deal with the highlight areas using special operation in the process of expansion, but separates the highlight areas processing from the dynamic range expanding step, which reduces the complexity of the expansion and help obtaining high quality HDR images. The algorithm first detects the highlight areas, and then pre-processes them, finally expands the image to HDR. In brief, the separation scheme replaces the complicated treatment to

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highlight areas in the process of expansion, which decreases artifacts and facilitates the expanding step.

2. ALGORITHM DESCRIPTION

The proposed algorithm consists in three stages: highlight areas detection, highlight areas pre-processing and dynamic range expansion. We use the difference between the original image and the Modified Specular Free (MSF) image to detect the highlight areas. The MSF image is obtained by adding the mean of the minimum of RGB color value of the original image to the Specular Free (SF) image as:

$$MSF_i(x,y) = SF_i(x,y) + \overline{I}_{\min}, \tag{1}$$

where $i \in \{r,g,b\}$, $\overline{I}_{\min}$ is the mean of $I_{\min}(x,y)$ for all the pixels in the original image I. The SF image is calculated by subtracting the minimum of RGB color value in each pixel.

$$SF_i(x,y) = I_i(x,y) - \min\left(I_r(x,y), I_g(x,y), I_b(x,y)\right), \tag{2}$$

The difference $d_i(x,y)=I_i(x,y)-MSF_i(x,y)$ is used to detect the highlight pixels:

$$pixel \in \begin{cases} highlight\ areas & if\ \ d_i(x,y) > th\ \ for\ all\ i \\ non\ highlight\ areas & otherwise \end{cases}, \tag{3}$$

The th is set to $\overline{I}_{\min}$. Fig. 1 shows the highlight areas detection results.

After highlight detection, a highlight removal technique based on Principal Component Analysis (PCA) is used to process the highlights. First, the image is represented by three principal components weighted by three eigenvectors:

$$I = V_1P_1 + V_2P_2 + V_3P_3, \tag{4}$$

where I is RGB value of image, V_i and P_i are principal component vectors and corresponding principal components respectively. It has been proved by experiments that in most cases the second principal component contains the part or whole of the highlight component [11]. A threshold value is set to compare with the fidelity ratio FR_i to detect whether the second largest principal component contains highlight component. If the threshold value is bigger than the fidelity ratio, the second principal component was detected as highlight component. It will not be used in image reconstruction. The threshold is set to 0.02. FR_i is defined as:

$$FR_i = \frac{\sigma_i}{\sum_{j=1}^{3}\sigma_j},\ \ i = 1,2,3 \tag{5}$$

where σ_i, i=1,2,3 is the i^{th} eigenvalue. The first principal component still contains some highlight part sometimes. So, histogram equalization was applied in the first principal component. The reconstructed image can be expressed as:

$$I_{rec} = \begin{cases} V_1P_h + V_3P_3 & if\ \ P_2\ contains\ highlights \\ V_1P_h + V_2P_2 + V_3P_3 & otherwise \end{cases}, \tag{6}$$

where P_h is histogram equalized principal component and I_{rec} is the reconstructed image.

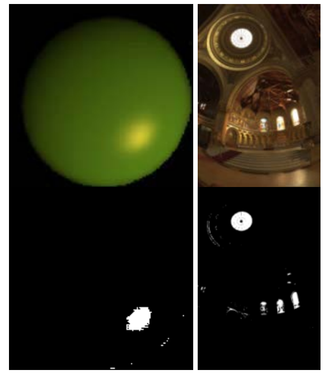

Fig. 1. Original LDR images (top) and the detected highlight areas (bottom).

From the experiments, we found that the color of the reconstructed image I_{rec} has shifted. Thus, the second order polynomial transformation is used to correct the color.

After highlight removal, the image becomes more natural than before highlight processing. According to the results of Akyuz [6], the image is expanded linearly as:

$$L_h = I_h \frac{L - L_{\min}}{L_{\max} - L_{\min}}, \tag{7}$$

where L is the luminance of the pixel being scaled, $L_{\min}$ and $L_{\max}$ are the minimum and maximum luminance of the input image respectively, and I_h is the maximum input intensity of the HDR display. This operation was applied to all pixels individually.

3. EXPERIMENTAL RESULTS

We chose a novel image quality metric [12] and a physiological tone mapping operator [13] to test and evaluate the algorithm. Meanwhile, using a set of test images (some of them are shown in Fig. 2), we compared the proposed approach with other three schemes: Piece-Wise Function (PWF) [7], Inverse Tone Mapping (ITM) [8] and LDR2HDR [9]. All algorithms are implemented with Matlab2011b on Intel Core i5-2520M CPU @ 2.5GHz, 4.00GB RAM, win32 system. The maximum illumination of HDR display is set to 3000cd/m^2, according to Brightside's 37" HDR monitor.

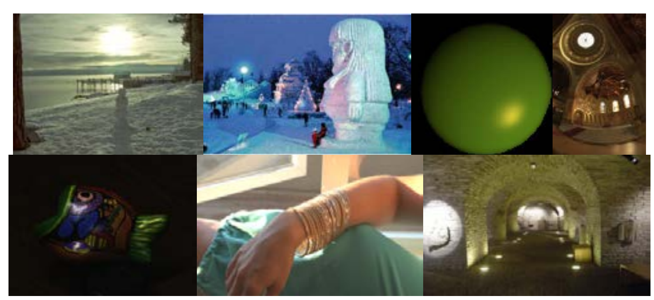

Fig. 2. A subset of test LDR images, from top-left to right-down: Tahoe, Plaza, Ball, Church, Fish, Woman, and Room.

Fig. 3. Metric result images, from left to right: PWF, ITM, LDR2HDR and proposed. Red, green and blue identify contrast reversal, loss of visible contrast and amplification of invisible contrast.

3.1. Image metric results

We compare the generated HDR images by each algorithm in the comparison with the corresponding LDR images using the image quality metric. The metric can detect three types of distortion and generate a summary image to indicate the three kinds of distortion: red pixel represents reversal of contrast (the contrast polarity is reversed in the HDR image with respect to the LDR image), green pixel means loss of visible contrast (visible in the LDR image and not visible in the generated HDR image) and blue pixel identifies amplification of invisible contrast (not visible in the LDR image and visible in the generated HDR image). The metric result images are shown in Fig. 3. Moreover, we quantitatively compute the percentage of red, green and blue pixels of the metric result images. Table 1 displays these percentage values, the higher blue percentage values and the lower red and green percentage values indicate the better performance of the algorithm, and vice versa.

3.2. Tone mapped versions

Because of the limitation of the medium, the HDR images cannot be shown in the paper directly. They are compressed by a novel physiological tone mapping operator [9] to LDR and shown in Fig. 4. These images help comparing the effectiveness of four algorithms considered in the comparison intuitively.

3.3. Results analysis

In Fig. 3, the metric results of the proposed method have more blue pixels and little red and green pixels than that of other algorithms, which means that the proposed approach can excavate more important image details and introduce little artifacts than other schemes. The red, green and blue percentages in Table 1 also indicate the good performance of the proposed method quantitatively.

The tone mapped images in Fig. 4 illustrate that our algorithm can obtain natural images, recover the details in highlight areas, and does not result in obvious distortion.

In brief, the experimental results and the image quality metric show that the proposed method works well for images with highlight areas. Furthermore, the separation of the highlight areas processing and dynamic range expansion facilitates the expanding step and avoids artifacts, which favors the generation of the high quality HDR images.

4. CONCLUSIONS

In this paper, a new dynamic range expansion approach is presented for generating HDR images from LDR images. Unlike the existing expansion algorithms, the proposed approach separates the highlight areas processing by highlight removal technique from the dynamic range expanding step, instead of sophisticated treatment to the highlight areas during expanding. This facilitates the expansion method and lowers the image distortion.

Table 1. Red, green, blue pixel percentage of metric result images: larger blue values indicates more detail reveal; larger red values means more contrast reversal; and larger green values denotes more contrast loss

	PWF			**ITM**			**LDR2HDR**			**Proposed approach**		
Test image	red (%)	green (%)	blue (%)	red (%)	green (%)	blue (%)	red (%)	green (%)	blue (%)	red (%)	green (%)	blue (%)
Fish	1.430	8.630	89.05	1.070	1.120	94.48	11.72	7.690	80.55	7.210	0.020	92.70
Woman	2.590	23.80	3.980	1.680	2.360	22.30	0.080	47.74	0.600	1.070	3.130	45.25
Church	5.330	10.04	57.00	3.290	17.36	29.92	5.900	15.02	52.10	4.690	3.240	73.58
Room	3.920	18.88	55.68	3.040	9.190	39.50	4.100	30.63	46.48	0.450	0.350	89.43
Tahoe	8.190	13.30	9.730	7.410	6.290	4.910	9.480	25.54	5.810	6.990	6.730	11.88
Plaza	19.97	25.20	10.41	14.39	9.960	8.650	20.88	34.27	9.310	9.510	1.830	27.44
average	**6.905**	**16.64**	**37.64**	**5.147**	**7.713**	**33.29**	**8.693**	**26.81**	**28.58**	**4.985**	**2.550**	**56.72**

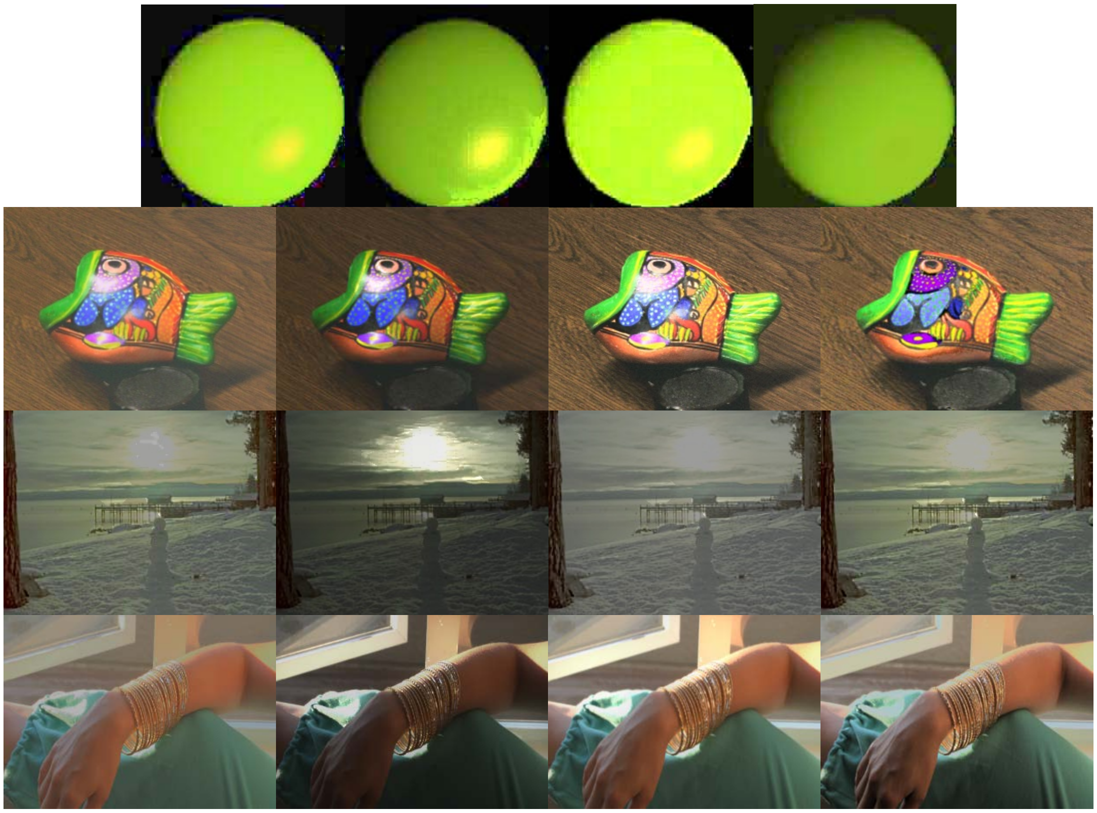

Fig. 4. Tone mapped versions, from left to right: PWF, ITM, LDR2HDR and proposed.

The experiments show that the proposed method works well for images with highlight areas, it can reveal more image details with little negligible contrast loss and reversal than the algorithms considered in the comparison. The images generated are more favorable and natural.

The proposed method is not suitable for video processing because of the second order polynomial transformation used for color correction. Thus, in the following work, we would like to explore other color correction techniques to make the proposed method applicable for video. Moreover, we also want to optimize our scheme and implement it on hardware embedded system.

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