HDR Image from Single LDR Image after Removing Highlight

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Abstract–**A low dynamic range (LDR) image that contains highlight does not provide proper information at the highlight area. Besides, all area of the image may not be exposed properly. Removing the highlight and then converting the image to the high dynamic range (HDR) image will increase the quality of the image from visual perception. In this paper, we propose a method for removing the highlight from an LDR image and convert the highlight free image to HDR image by using tone mapping operator (TMO). After detecting highlight area of an image, modified specular free (MSF) image is used to remove highlight part from the LDR image. Then, the highlight free LDR image is converted to HDR image by TMO. Finally, we have measured the quality of our output image to show that output image has better dynamic range than the input image.**

Index Terms- **Highlight, LDR, HDR, TMO, MSF.**

I. INTRODUCTION

Image processing algorithms are used for extracting information from image in different type of applications. But highlight hides the perfect information of any surface of the image and it adds extra difficulty to any image processing algorithm. Dynamic range of an image depends on the exposure quality and visible quality of the scene. If a well exposed LDR image is included highlight, it cannot ensure the better quality of the visibility. For this reason, before expansion an LDR image to HDR image it is badly needed to remove highlight from LDR image.

Highlight of an image can be defined as hiding actual color of the surface of an image. Fig. 1 shows the reflection of a ray of light [1]. Reflection of a ray of light is the combination of diffuse reflection and specular reflection. The highlighted parts are the combination of diffuse reflection and specular reflection where specular reflection dominates. They are well described in dichromatic reflection model [1]. In our paper, we try to extract the actual diffuse reflection component from the highlighted area which helps to increase the dynamic range of the image. Then expanding our highlight free LDR image to HDR image by using tone mapping operator.

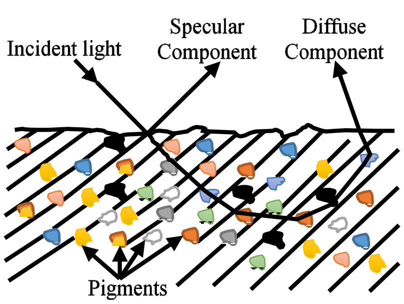

Fig. 1. Reflection components with specular and diffuse component from inhomogeneous surface.

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We describe our research in some different sections. In section II, we discuss some literatures of this type of works. In section III, we describe our proposed algorithm, we show some simulation result in section IV and finally in section V, we conclude.

II. RELATED WORKS

A. Works on Highlight Removing

There are many researches on removing highlight from image. Tan et al. [2] removed highlight from input image by comparing the intensity logarithmic differentiation of an input image and its specular free image iteratively [2]. Yoon et al. [3] showed that specular-free two-band image belongs to the diffuse reflection component of an input image by comparing the local ratios of input image and specular-free two-band image [3]. But they experimented images, under the uniform illumination of color and they also assumed that all pixels are chromatic, not saturated. Shen et al. [4] proposed a method to separate reflections based on the error analysis of chromaticity and appropriate selection of body color for each pixel [4]. Shen et al. [5] proposed another method based on adding an offset to modified specular free (MSF) image as its chromaticity is close to the diffuse chromaticity [5]. Yang et al. [6] proposed a method to remove highlight from image based on maximum diffuse chromaticity values which are propagated from diffuse pixels to specular pixels applying bilateral filter [6].

B. Works on Generation of HDR Image from LDR Image

There are many works on HDR image generation. Reinhard et al. [7] proposed a tone mapping method which did dodging and burning locally in high contrast region and low contrast region of LDR image. Dodging and burning is a technique which lightens or darkens the region relative to native region. Rempel et al. [8] proposed reverse tone mapping algorithm for boosting the dynamic range of images for viewing in high dynamic range displays [8]. The algorithm was described as the combination of contrast stretching and brightness enhancement to saturated regions. Banterle et al. [9] proposed a new framework of inverse tone mapping operator that could make LDR image to HDR image. They boosted up the LDR image to HDR image by linear interpolation of original LDR image, expanded LDR image by inverse tone mapping

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operator. Huo et al. [10] proposed a method of generating HDR image from LDR image by removing highlight and linear expansion of highlight free LDR image. They removed highlight by using principal component analysis (PCA) and polynomial transformation.

III. Proposed Method

In this paper, we first detect highlight area, then calculate the MSF image and replace the corresponding highlighted pixels of MSF image to the original image. After replacing, there exist some brightness mismatch to the highlighted area which is solved by adjusting brightness to the highlighted area. The highlight free image is used to expand to HDR image by using tone mapping operator applying dodging and burning method. Here, we follow the MSF image of [5] and try to extract the exact diffuse component from the MSF image by varying the value of η_{MSF} in (3) from image to image. The block diagram of the proposed method is shown in Fig. 2. Now the proposed method is described in detail according to the block diagram of Fig. 2.

A. Highlight Area Detection

At the first stage of our proposed method, we have to detect highlight of the LDR image. For this reason, we calculate offset from [5] by using a threshold which is calculated by an approximated new value of η, described in [5] and it is used for highlight detection. For detecting highlight, the following equations are necessary:

$$I_{\min}(x,y) = \min(I_i(x,y)) \tag{1}$$

$$\begin{Bmatrix} I_{hd}(x,y) \\ I_{dd}(x,y) \end{Bmatrix} = \begin{cases} highlight & , offset_{hd}(x,y) - \overline{I_{\min}} > \overline{I_{\min}} \\ diffuse & , Otherwise \end{cases} \tag{2}$$

In (1), $I_{\min}(x,y)$ is the minimum intensity value of pixel at position (x, y), $I_i(x,y)$ is the input LDR image where, $i \in \{r,g,b\}$. In (2), $offset_{hd}(x,y)$ is the offset for detecting highlight area calculated from [5], $I_{hd}(x,y)$ and $I_{dd}(x,y)$ contain logical value 0 and 1, in $I_{hd}(x,y)$ 0 represents diffuse pixel and 1 represents highlight pixel, in $I_{dd}(x,y)$, 0 represents highlight pixel and 1 represents diffuse pixel, $\overline{I_{\min}}$ is the average of $I_{\min}(x,y)$. The size of $I_{hd}(x,y)$ and $I_{dd}(x,y)$ is equal to the size of $I_{\min}(x,y)$. Highlight areas are found in $I_{hd}(x,y)$. So, we use it for replacing the MSF image to original image. The value of η is approximated to 2.5 because it is experimented that this value can detect maximum number of highlight pixels with minimum number of diffuse pixels as highlight where the value of η was approximated to 0.5 in Shen et al. [5] method. In Fig. 3(a)-3(j), the simulation results of highlight area detection are shown for our proposed method as well as Shen et al. [5] method. The simulation results also show the comparison of both methods. The yellow box

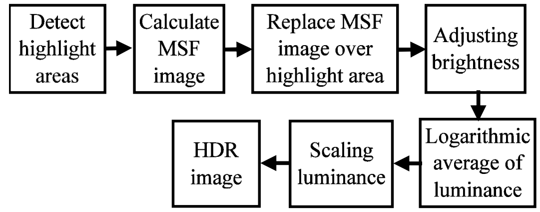

Fig. 2. Block diagram of the proposed method.

mentioned in Fig. 3(a), 3(b) and 3(d) indicates the actual highlight area and the orange box mentioned in Fig. 3(b) and 3(d) indicates the detected highlight area by Shen's et al. [5] method and our method, respectively. The area of orange box in Fig. 3(b) is larger than the area of orange box in Fig. 3(d). So, our method detects less number of diffuse pixels as highlight pixels of Fig. 3(a). In Fig. 3(g) and 3(i), the blue marked area indicates the diffuse area which is detected as highlight area by Shen's et al. [5] method and our method, respectively. In that case, the blue marked area in Fig. 3(g) is larger than the blue marked area in Fig. 3(i). These scenarios of Fig. 3(b), 3(d), 3(g) and 3(i) imply that our highlight detection method detects very less number of diffuse pixels which is very negligible than Shen's et al. method [5]. So, the value of η (= 2.5) minimizes the number of detected diffuse pixels as highlight than Shen's et al. [5] approximation (η = 0.5).

B. Calculating MSF Image

Now for calculating MSF image, we need to calculate its threshold and offset from the following equations:

$$T_{MSF} = \overline{I_{\min}} + \eta_{MSF} I_{std} \tag{3}$$

$$offset_{MSF}(x,y) = \begin{cases} T_{MSF}, & I_{\min}(x,y) > T_{MSF} \\ I_{\min}(x,y), & Otherwise \end{cases} \tag{4}$$

$$I_{MSF,i}(x,y) = I_i(x,y) - I_{\min}(x,y) + offset_{MSF}(x,y) \tag{5}$$

In (3), T_{MSF} is the threshold for MSF image, I_{std} is the standard deviation of $I_{\min}(x,y)$ and η_{MSF} is the coefficient of I_{std} . In (4), the $offset_{MSF}(x,y)$ is the offset at (x,y) position for MSF image. In (5), $I_{MSF,i}(x,y)$ is the MSF image and $i \in \{r,g,b\}$.

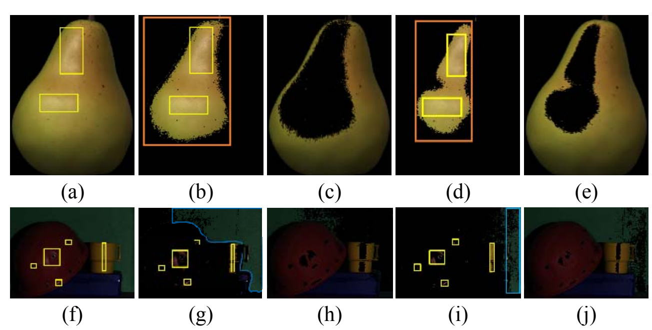

Fig. 3. (a), (f) are input images, respectively, Yellow Pear and Helmet; (b), (g) are highlight detected areas by Shen et al. method [5]; (c), (h) are diffuse detected areas by Shen et al. method [5]; (d), (i) are highlight detected areas by our method and (e), (j) are diffuse detected areas by our method.

C. Replacing MSF Image and Adjusting the Brightness

Now we replace the corresponding highlight pixels of MSF image to the original image. The replaced MSF image contains mismatch of brightness. So, we brighten the pixels in the highlight detected area of replaced MSF image as much as it is required by using the following equations:

$$I_{MSF,BR,i}(x,y) = I_{MSF,i}(x,y) I_{hd}(x,y). \left(1+\exp\left(-14\left(\frac{L_{MSF}(x,y)}{255}\right)^{1.6}\right)\right)V \tag{6}$$

$$L_{MSF}(x,y) = 0.27\,R_{MSF}(x,y) + 0.67\,G_{MSF}(x,y) + 0.06\,B_{MSF}(x,y) \tag{7}$$

In (6), $I_{MSF,BR,i}(x,y)$ is the brightened MSF pixels in highlight detected area, V is the multiplying constant which varies image to image and $L_{MSF}(x,y)$ is the luminance component of $I_{MSF,i}(x,y)$ which is formulated in (7) [7]. Equation (6) is described as the non-decreasing function to brighten the under-exposed regions of the image [11] but we use it only to the highlight area because after replacing MSF image into the highlight area, it contains dark colored pixels which halt the extraction of actual diffuse pixel. For this reason, the highlight part of MSF pixel is brightened by (6). After that, we produce the final highlight free image by using the following equation:

$$I_{HF,i}(x,y) = I_i(x,y) I_{dd}(x,y) + I_{MSF,BR,i}(x,y) \tag{8}$$

D. Logarithmic Average of Luminance

Now, we will make HDR image from the highlight free LDR image by using tone mapping operator. This operator gives a new scale of luminance value for making image more natural. So, for HDR processing the first step is to calculate the log average of luminance value [7] of $I_{HF,i}(x,y)$ image by using the following equation:

$$\overline{L_{LHF}} = \exp\left(\left(\sum_{x=1,y=1}^{x=r,y=c} \log\left(\delta + L_{HF}(x,y)\right)\right)/ N\right) \tag{9}$$

In (9), the $L_{HF}(x,y)$ is the luminance of $I_{HF,i}(x,y)$ image which is calculated in the same manner of $L_{MSF}(x,y)$ in (7), $\overline{L_{LHF}}$ is log average luminance value [7] of the $I_{HF,i}(x,y)$ image where suffix 'LHF' indicates the logarithmic average of $I_{HF,i}(x,y)$ image, N is the total number of pixels, r and c are row and column of $I_{HF,i}(x,y)$ image and δ is 1/256 [9]. δ is a very small value to avoid the evaluation of log zero [9].

E. Scaling Luminance

Now we have to calculate the value of scaled luminance by the scene key value [7]. From [7], the key value of a scene is defined as the subjective dark and light condition [7]. The luminance can be scaled by the following equation:

$$L(x,y) = \left(a / \overline{L_{LHF}}\right) L_{HF}(x,y) \tag{10}$$

In (10), $L(x,y)$ is the scaled luminance, a is the key value of the $I_{HF,i}(x,y)$ image [7] which is varied image to image. After that, the tone mapped luminance value is calculated from the following way:

$$L_d(x,y) = L(x,y) / \left(1 + L(x,y)\right) \tag{11}$$

Equation (11) can be extended to allow high luminance to burn out in a controllable fashion like the following equation [7]:

$$L_d(x,y) = L(x,y)\left(1 + \left(L(x,y) / L_{white}^2\right)\right) / \left(1 + L(x,y)\right) \tag{12}$$

In (12), $L_d(x,y)$ is the tone mapped luminance value. Actually, (12) blends between (11) and linear mapping [7]. Here, we vary the value of L_{white} in (12) from image to image for better HDR image.

F. Measuring RGB value for HDR Image

After that, we have to measure new RGB value for HDR image from the following equation [9]:

$$I_{hdr,i}(x,y) = I_{HF,i}(x,y) L_{HF}(x,y) / \left(255 L_d(x,y)\right) \tag{13}$$

In (13), $I_{hdr,i}(x,y)$ is the HDR image and $i \in \{r,g,b\}$.

IV. Simulation Results

In Fig. 4, the simulation results are shown for three test images. Here, the input LDR images are called *fish*, *face* and *hen* shown respectively in Fig. 4 a(i), b(i) and c(i). In *fish* image, the highlight part is shown in Fig. 4 a(ii). In Fig. 4 a(iii), for creating MSF image we set the value of η_{MSF} 0.5, in Fig. 4 a(v), we set the value of V as 1.025 for removing the brightness mismatching and in Fig. 4 a(vi), we set the value of a and L_{white} as 0.05 and 0.35, respectively. For rest of the images, the parameters which are varied are listed in Table I. We calculate the value of standard deviation of luminance for the input LDR images as well as output HDR images. We choose the value of a and L_{white} so that we can achieve the minimum standard deviation of output HDR images. Using (7), we calculate the luminance of HDR image. We choose η_{MSF} and V by human visual system for better highlight free image. From the sense of HDR definition, the average intensity of the HDR image will be greater than the average intensity of LDR image and the luminance of HDR image will be less deviated than that of LDR image. It is happened because from the definition of LDR image, there exist highly exposed and weakly exposed area but in HDR image, almost every area is well exposed. Highly and weakly

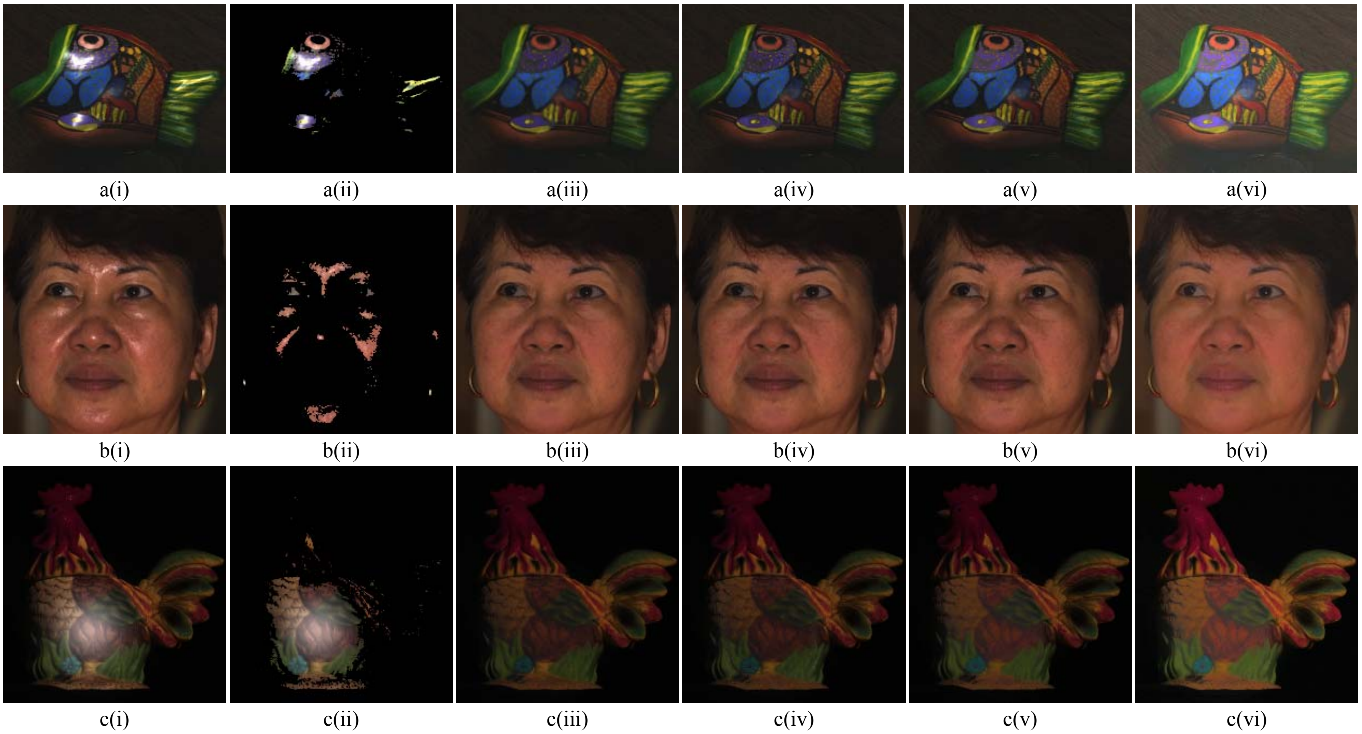

Fig. 4. a(i), b(i), c(i) are input LDR images; a(ii), b(ii), c(ii) highlight detected areas; a(iii), b(iii), c(iii) MSF images; a(iv), b(iv), c(iv) MSF replaced images; a(v), b(v), c(v) Highlight free images and a(vi), b(vi), c(vi) output HDR images.

exposed area increase the total standard deviation of luminance while well exposed area decreases total standard deviation of luminance. For this reason, our target is to convert the highly and weakly exposed area close to the well exposed area. We convert highly exposed area to well exposed area by using highlight removal technique and convert weakly exposed area to well exposed area by using tone mapping operator with dodging and burning technique mentioned in (12). In Table I, We show that the standard deviation of the input LDR images is minimized after processing them to HDR images. It also ensures the well visibility of the LDR images. We get the larger difference in standard deviation between LDR image and HDR image 3.65 for fish image.

TABLE I
STANDARD DEVIATION OF LDR AND HDR IMAGES

Images	Standard Deviation of LDR and HDR Image for Different Parameters					
	η_{MSF}	V	a	L_{white}	STD (LDR)	STD (HDR)
Fish	0.5	1.025	0.05	0.35	30.27	26.62
Face	1.5	1.000	0.09	0.40	31.45	28.44
Hen	0.2	0.825	0.015	0.45	31.49	29.74

V. CONCLUSION

In this paper, it is shown that the HDR contents of an LDR image are explored by removing highlight and recovering object details in weakly exposed region. The quality of the HDR image is measured by comparing standard deviation of input LDR and output HDR image. At the time of our HDR conversion, we select the scene key value a and L_{white} experimentally. We do not calculate the parameters in any specific way. But in future, we try to develop an algorithm to detect the value of these parameters properly.

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