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새로운 MSF 이미지와 CLAHE를 이용한 다이나믹 레인지 향상

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Dynamic Range Enhancement Using New MSF Image and CLAHE

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ABSTRACT

Low dynamic range (LDR) image may contain low-light and highlight areas due to the limitations of the dynamic range of LDR image sensor. To overcome this, high dynamic range (HDR) images have been developed with rich colors such as those seen by the human eye. Most HDR images are produced by using a good image sensor or by composing photographed pictures under different exposure conditions. In this paper, we propose a method to enhance the dynamic range of a single LDR image by removing the specular component from highlight pixels and strengthening the brightness of low-light area with preserving actual color. Next, we apply a contrast limited adaptive histogram equalization (CLAHE) to expand the dynamic range by varying the R, G, and B values according to the brightness. We verify real-time use based on the execution speed of the algorithm. We evaluate our proposed method by using natural image quality evaluator (NIQE) and histogram balance (HB) quality metrics. We also show the improvement in the highlight and low-light areas and confirm that our results can be applied in the field of image recognition.

Key Words : HDR, Highlight, Low-light, MSF, CLAHE, Camera

Ⅰ Introduction

In the case of standard dynamic range (SDR), that is, in the case of a low dynamic range (LDR) image, the dark areas are too dark[1, 2] and the bright areas are too bright and appear white[3, 4]. It brings problem to the human visual system for better visibility of a scene. To overcome this, high dynamic range (HDR) ivmages[5] have been developed. The advantage of HDR is that it can realize the difference in brightness actually felt by humans.

Dynamic range of an image refers to the difference between the darkest and the brightest intensity values in an image. Brightness is expressed in candela per square meter (cd/m2), also called nits. In other words, each display has characteristics such as 0.3 ~ 1000 [cd/m2] or 0.1 ~ 1200 [cd/m2]. The ratio of the lightest level to the darkest level is called the dynamic range, and a display with a wide

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dynamic range is called an HDR display[5]. Figure 1 shows the brightness of light that exists in nature and the range of brightness expression of displays.

Dynamic range expansion in an image means recovering information in dark and bright areas and making the distribution of brightness more uniform. Therefore, in this paper, dynamic range expansion is compared with input images using natural image quality evaluator (NIQE) and histogram balance (HB) metrics, and improved changes are observed in both highlight and low-light areas.

In order to generate an HDR image, two or more images in different exposure conditions are usually synthesized[6,7]. As in Fig. 2, three photographs are taken at high speed with overexposure, standard exposure, and insufficient exposure. In the resultant HDR image, the bright region is synthesized with the image of insufficient exposure and the dark region is synthesized with the image of overexposure. With the advancement of technology, digital cameras and smartphones are equipped with these functions. However, it takes a long time to synthesize three pictures, so it is not suitable for shooting moving objects or movies[8].

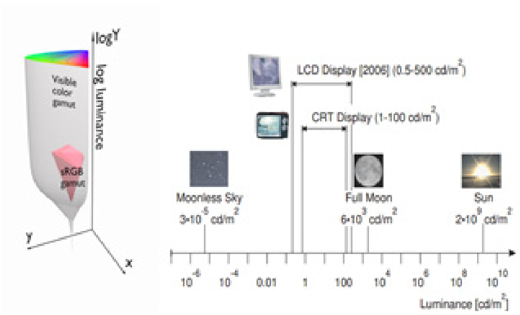


Fig. 1. Display and brightness range of several objects.

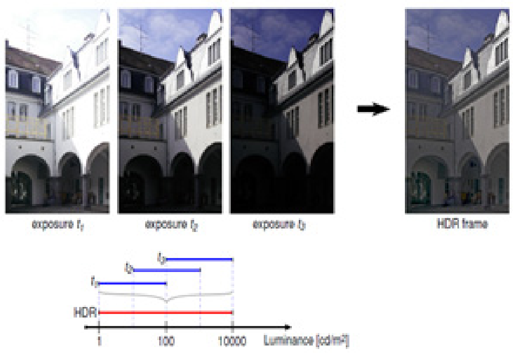


Fig. 2. Generation of an HDR image by fusing photos from different exposures.

In this paper, we propose a method to obtain an enhanced dynamic range image from a single LDR image. To maintain the color of the input image with pixel-by-pixel computation, we propose a new modified specular free (MSF) image technique as well as a brightness enhancement(BE) technique corresponding to the input image. Then, contrast limited adaptive histogram equalization (CLAHE)[9], which is a kind of histogram equalization (HE), is used to reform the brightness values while maintaining the colors of the input image. Next, several images are experimented for application in the field of image recognition.

The remainder of this paper is organized as follows: Section II discusses related works, Section III describes the proposed algorithm, Section IV describes the experimental results, and Section V concludes this study.

Ⅱ. Related Research Works

As the most widely used HDR image generation method, multiple LDR images with different exposures can be applied. Well-known methods using multiple images use exposure variations between sequential photographed LDR images and synthesize them[6,7].

Tan et al.[10] separated specular and diffuse reflections using a 'specular-to-diffuse mechanism' by using the characteristics of specular components and diffuse components in the chromaticity space.

He et al.[11] separated the reflection and diffusion components in a single image using the independent component analysis for the dichromatic reflection model[12].

Koirala et al.[13] created a specular-free image by subtracting the smallest R, G, and B values of each channel of the input image from all channels, and created an MSF image based on the specular-free image. Highlight components were obtained through principal component analysis, and highlights were removed by polynomial transformation.

Huo et al.[3] used Koirala's method to reconstruct the image through a polynomial transformation after finding the highlight pixels and then extended the LDR image to an HDR image. Kim et al.[14] generated HDR images through the tone-mapping technique using the Retinex algorithm.

Paper[15-17] say that histogram equalization (HE) can stretch the dynamic range of image. Paper[16] also says that the HE can expand the dynamic range by enhancing the contrast of an image in gray-level's image domain.

Compared to these algorithms, our method gives better image enhancement using the idea of the new MSF image, BE, and CLAHE, which has advantages in computational time. At the same time, our method also expands the dynamic range.

Ⅲ. Proposed Method

Figure 3 shows the block diagram of the proposed method. In the following subsections, we will describe our proposed algorithm step by step.

Fig. 3. Block diagram of the proposed method.

3.1 Modified Specular Free Image

The contrast of the image can be increased directly through the use of CLAHE without removing the specular component. However, in this case, there is a problem in that the information in the highlight regions cannot be recovered due to the specular components. Figure 4 shows the result of performing CLAHE directly to the input image.

In Fig. 4, we can see the highlight phenomenon in regions under the eye and near the fin of the fish.

Fig. 4. Input image and the corresponding CLAHE result.

To overcome this problem, we propose a new type of MSF image. The specular component is defined as white in[10,13]. Koirala[13] subtracts the smallest value of R, G, and B from each of R, G, and B, respectively, for each pixel of the image to create a specular-free (SF) image. The MSF images were generated by adding the average of those smallest values to the SF image. It is the conventional way to generate the MSF image. In this paper, a new MSF image was created by further modifying this method. Equation (1) expresses the MSF image of Koirala[13].

$$MSF(x,y) = I_C(x,y) - \min(I_r(x,y), I_g(x,y), I_b(x,y)) + Offset \tag{1}$$

where (x, y) is the coordinate of the image and $c = \{r,g,b\}$. $I_C(x,y)$ represents R, G, and B values of the input image, and $\min(I_r(x,y), I_g(x,y), I_b(x,y))$ is the minimum value among the R, G, and B values at the position (x, y). In this paper, the offset value in the conventional MSF is used as an initial value as in (2)[3,13].

$$Offset = E(\min(I_r(x,y), I_g(x,y), I_b(x,y))) \tag{2}$$

where E represents the average. It can easily be seen that the hue value of the MSF image is the same as the hue value of the input image through (3) and (4).

$$H = \begin{cases} 0, & \text{if } \max = \min \\ (60^\circ \times \frac{G-B}{\max - \min}) + 0^\circ, & \text{if } \max = R \\ (60^\circ \times \frac{B-R}{\max - \min}) + 120^\circ, & \text{if } \max = G \\ (60^\circ \times \frac{R-G}{\max - \min}) + 240^\circ, & \text{if } \max = B \end{cases} \tag{3}$$

where max represents max (R, G, B) and min represents min (R, G, B). Equation (1) is applied to (3), and Eq. (3) can be written as follows:

$$H = \begin{cases} (60^\circ \times \frac{(G - \min + Offset) - (B - \min + Offset)}{(\max - \min + Offset) - Offset}) + 0^\circ \\ (60^\circ \times \frac{(B - \min + Offset) - (R - \min + Offset)}{(\max - \min + Offset) - Offset}) + 120^\circ \\ (60^\circ \times \frac{(R - \min + Offset) - (G - \min + Offset)}{(\max - \min + Offset) - Offset}) + 240^\circ \end{cases} \tag{4}$$

The added min and offset are canceled and can be seen to be equal to (3). That is, the MSF image has the effect of removing specular noise from the input image without changing the color of the input image. Fig. 5 shows an example of an MSF image assuming an offset of 10.

The overall average of the minimum value of each pixel is obtained, and this value is set to the initial offset. At this time, if the value of $I_C(x,y)$ in (1) is larger than 255, it causes overflow. In the conventional MSF, when overflow occurs, only the corresponding value is changed to 255. In this case, however, the hue identity in (3) and (4) is not maintained. In this paper, when overflow occurs it is changed to 255 and keeps the same hue value by subtracting R, G, B by the same difference. Also, if the initial offset is large, information recovery in low-light area may not be performed properly. For example, when the pixel value is (20, 30, 5) and the offset is 150, the MSF of (1) becomes (165, 175, 150). Figure 6 shows the results for this example.

This technique maintains the color and increases brightness only, but it makes the image too bright compared to the input image. In the proposed method, if the offset is larger than the maximum value among the R, G, and B components of the pixel, it is adjusted to be smaller than the maximum value. Applying this to the above example, the offset is set to 29 and the result is shown in Fig. 7.

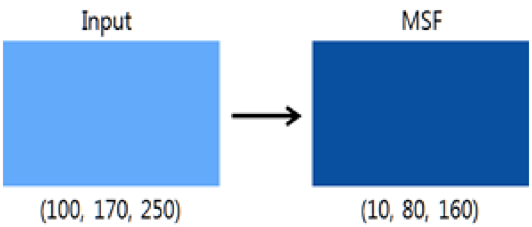


Fig. 5. Example of MSF image for a bright type pixel.

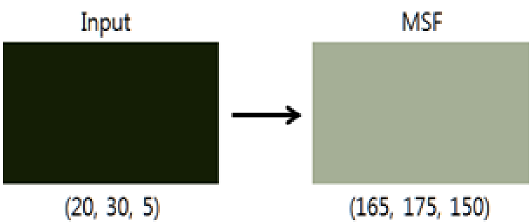


Fig. 6. Example of conventional MSF image for a dark type pixel.

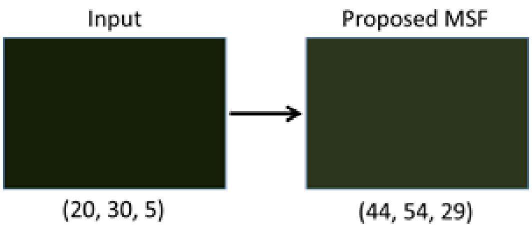
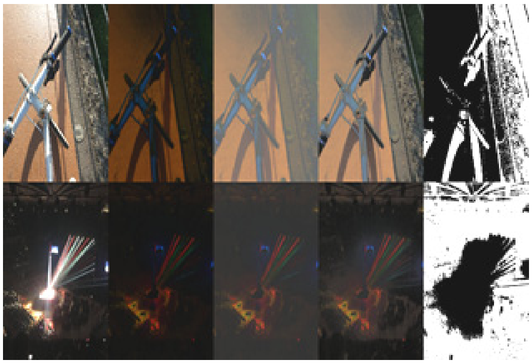


Fig. 7. Example of proposed MSF image for a dark type pixel.

In the proposed method, the offset value is adjusted to the constraint based on the initial value. Equation (5) shows the newly proposed method of the MSF image of (1).

$$\begin{cases} \mathrm{if}(\max = 255, \min = 0)\, MSF(x,y) = I(x,y) \\ \mathrm{if}(\max - \min + offset > 255) \\ \qquad Offset = Offset - ((\max - \min + Offset) - 255) \\ \qquad MSF(x,y) = SF(x,y) + Offset \\ \mathrm{if}(Offset > \max) \\ \ Offset = \max - 1 \\ \qquad MSF(x,y) = SF(x,y) + Offset \\ else\ \ MSF(x,y) = SF(x,y) + Offset \end{cases} \tag{5}$$

Figure 8 shows the input image, SF image, conventional MSF image, proposed MSF image, and the pixels (white part) to which the new offset value is applied.



(a) (b) (c) (d) (e)

Fig. 8. (a) Input image; (b) SF image; (c) Conventional MSF image; (d) Proposed MSF image; (e) Pixels (white) where new offset value is applied.

3.2 Brightness Enhancement

Although color and geometrical information is maintained from the input image to the MSF image, if CLAHE is directly applied to the MSF image, information may be lost in the highlight pixels as shown in Fig. 9. Besides, the effect on the light source (the intention to brighten the light) may disappear. In order to overcome the limitations of the MSF image, we propose a method to emphasize the bright region of the input image by enhancing the brightness of the image and to recover the information about the light source while maintaining the effect and color information of the light source.

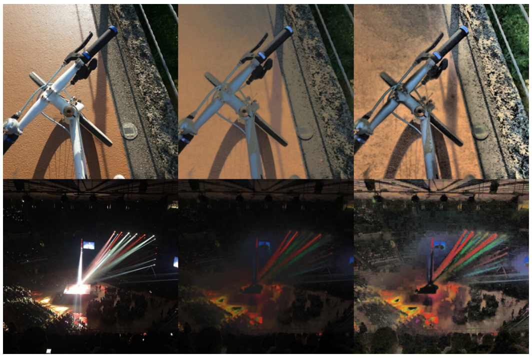
By using the input image and the MSF image, we maintain the ratios of R, G, and B and increase the brightness. The maximum channel value of each pixel may indicate the light source area. Therefore, we take the ratio of the maximum channel value of the input image to the proposed MSF image. The ratio is defined in (6).

$$Ratio(x,y) = I_{\max\,of\,Input}(x,y) / I_{\max\,of\,MSF}(x,y) \tag{6}$$

If this ratio is multiplied by the R, G, and B channel values of each pixel of the MSF image, the BE image shown in (7) is obtained.

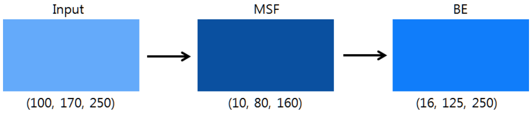
$$I_{Brightness\,Enhancement}(x,y) = I_{MSF}(x,y) \times Ratio(x,y) \tag{7}$$

Since the MSF image contains the offset value, the same hue value can be maintained by multiplying the R, G, and B channels by the same ratio, as shown in (8). Figure 10 shows an example of obtaining the BE effect while assuming that offset is 10 and maintaining the same Hue value after applying (7).



(a) (b) (c)

Fig. 9. (a) Input image; (b) Proposed MSF image; (c) CLAHE applied on proposed MSF image.



(a) (b) (c)

Fig. 10. (a) Input image; (b) Proposed MSF image (offset=10); (c) BE image.

$$H = \begin{cases} 0, & \text{if } \max = \min \\ (60^\circ \times \dfrac{ratio(G-B)}{ratio(\max - \min)}) + 0^\circ, & \text{if } \max = R \\ (60^\circ \times \dfrac{ratio(B-R)}{ratio(\max - \min)}) + 120^\circ, & \text{if } \max = G \\ (60^\circ \times \dfrac{ratio(R-G)}{ratio(\max - \min)}) + 120^\circ, & \text{if } \max = B \end{cases} \tag{8}$$

The BE process recovers the bright parts of the input image without changing the color of the light source. Figure 11 shows the result of the MSF and BE process on the picture taken with 'Samsung Galaxy A5 2017'.

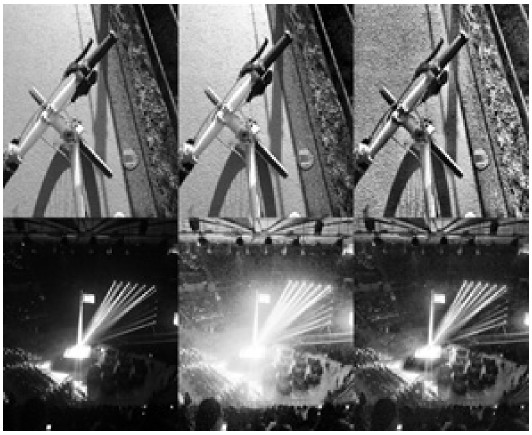
Fig. 11. (a) Input image; (b) Proposed MSF image; (c) Image after BE process.

3.3 CLAHE

In general, histogram equalization (HE) aims to flatten the histogram and stretch the dynamic range of entire image[15]. However, since there can be various bright and dark areas in the input image, if

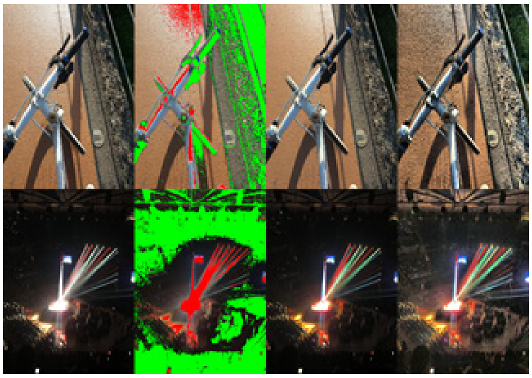
HE is applied, some parts of the image may become too bright to allow recognition of certain shapes in the image as shown in Fig. 12. To improve this, CLAHE[9] was developed. CLAHE is a method of dividing an image into smaller sections and then applying uniformity within each section. At this time, in a small section, if there is a small noise (i.e., an extremely dark or bright area exists in a small section), the desired result cannot be obtained because of this noise. In order to avoid this problem, if the value exceeds the contrast limit, the area is uniformly distributed to other areas. Therefore, CLAHE provides better visibility in the highlight and low-light areas than the HE. Figure 12 shows the brightness of the input image and the results of HE and CLAHE.

CLAHE also allows the recovery of low-light pixel information. When the CLAHE is applied, the low-light pixel values gain a brighter effect. Figure 13 shows an input image, highlight and low-light pixels (highlight is shown in red and low-light is shown in green), BE image, and the image after applying CLAHE with BE. The highlight phenomenon is overcome with the proposed MSF and BE process, while the low-light phenomenon is overcome through the use of CLAHE. Also, note that the color of the input image is maintained constant during the entire process.



(a) (b) (c)

Fig. 12. (a) Input image; (b) HE image; (c) CLAHE image.



(a) (b) (c) (d)

Fig. 13. (a) Input image; (b) Highlight and Low-light pixels; (c) BE image; (d) Applying CLAHE after BE.

Ⅳ. Experimental Results

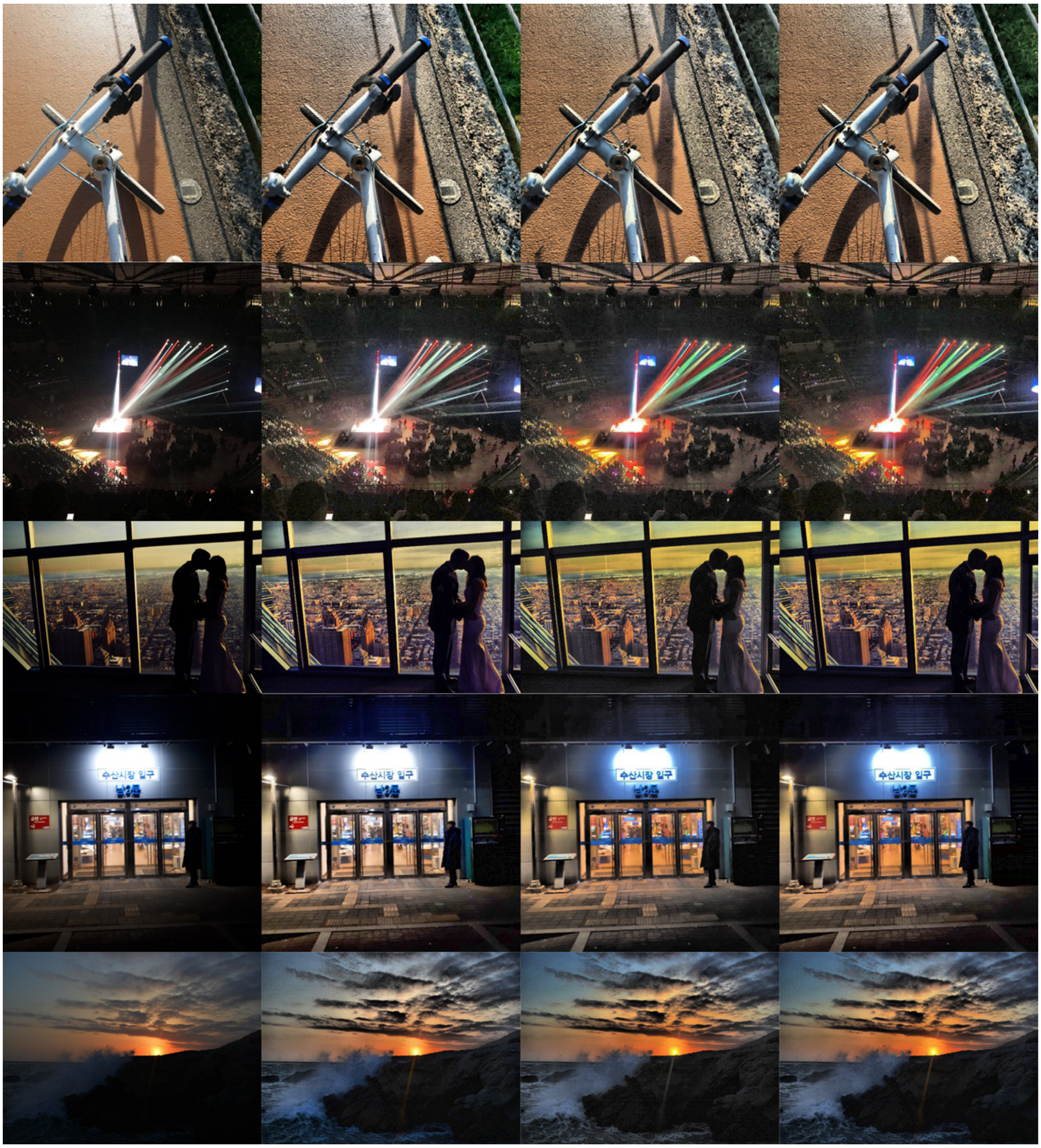
We applied the proposed algorithm under Visual Studio 2015 in a 64-bit Windows 7 environment and used the OpenCV library which is easy to image processing. The CPU of the computer was a Quad Core running at 3.50 GHz with 8.00GB of RAM. The size and execution speed of our experimental pictures are summarized in Table 1.

The 960×960-pixel Concert hall image had the longest running time at 55ms (roughly 18 fps). Considering that the size of standard definition (SD) video format (720×480) is one-third of the concert hall image size, a speed of 36 fps or more can be expected when processing SD frames and thus real-time processing is possible at 30 fps.

Figure 14 shows, from the left, the input image, the CLAHE image directly applied to the input image, the CLAHE image applied to the conventional MSF with BE, and the resulting image

Table 1. The size and execution time of our experimental pictures.

Number	Picture	Size	Execution time(ms)
1	Bicycle	480 × 480	17
2	Concert hall	960 × 960	55
3	Indoor	600 × 398	18
4	Building entrance	960 × 960	54
5	Sunrise	500 × 373	15



(a) (b) (c) (d)

Fig. 14. (a) Input; (b) Applying CLAHE directly to input image; (c) Applying CLAHE to conventional MSF image with BE; (d) Proposed output image.

of the proposed method (including proposed MSF, BE, and CLAHE). In the case of the Bicycle image, the visibility is better than the image of (c) in the upper right low-light region, and in the case of the Concert hall image, the visibility of the highlight region is improved in the proposed method than the CLAHE image directly applied to the input image. In the case of the Indoor image, the proposed method, in the skirt part, achieved better visibility than (c), and the light-fading phenomenon was also removed in front of the window frame. The visibility of the lighting part, which is the highlight area of the Building entrance image, as well as the visibility of the low-light area of sidewalk block were improved, and it can be seen that the vending machine on the right side of the image was clearer than (b) and (c). We also confirmed that the visibility of the rock part of the Sunrise image of the proposed method was better than that of (b).

In order to compare the results quantitatively, we used NIQE[18] and HB[19]. The smaller the value of NIQE, the better the quality. At the same time, as the distribution of brightness values becomes more uniform, i.e. dynamic range is expanded, HB becomes smaller and shows uniformity[19]. Table 2 compares each result using NIQE. The average NIQE values for the proposed method are relatively small and dynamic range performance is improved.

Table 3 compares each result using HB. The histogram of the proposed method is more uniform than the input image. The performance of the proposed method was slightly better than that of CLAHE image applied to a conventional MSF with BE.

Table 2. Comparison results using NIQE.

	Input Image	Applying CLAHE to conventional MSF with BE	Proposed result
Bicycle	4.9832	5.2849	5.3080
Concert hall	3.8993	3.2989	3.2704
Indoor	3.4664	4.3210	4.0040
Building entrance	4.8744	4.0053	4.0686
Sunrise	5.1667	4.5457	4.4810
Average	4.4767	4.29116	4.2264

Table 3. Comparison results using HB.

	Input Image	Applying CLAHE to conventional MSF with BE	Proposed result
Bicycle	108,516	111,488	109,310
Concert hall	1,217,638	932,362	927,784
Indoor	203,586	139,900	139,988
Building entrance	238,656	177,132	172,518
Sunrise	214,902	161,462	160,812
Average	396,659.60	304,468.80	302,082.40

Ⅴ. Conclusion

In this paper, we proposed a new MSF image to overcome the highlight phenomena due to the specularity of the input image. Brightness Enhancement was applied, and then the contrast was improved through CLAHE to overcome low-light phenomena. We expanded the dynamic range by improving the low-light phenomenon due to low light intensity as well as the highlight effect caused by the light source, and also by uniformly distributing the brightness. To verify this, we compared the input image, CLAHE image applied to conventional MSF with BE, and the proposed result. NIQE and HB values were used to quantitatively compare dynamic range quality. There was no significant difference in the numerical value, but it showed improvement relative to the input image. The proposed method overcomes the highlight and the low-light phenomena of images, and the outline becomes clear. We also demonstrated that real-time processing can be achieved using the proposed technique.

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