An Image Contrast Enhancement Scheme with Noise Aware Shadow-up Function

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***Abstract*--This paper proposes a novel image contrast enhancement method based on a noise aware shadow-up function. Images taken by digital cameras have low contrast in dark or bright regions. This is due to a limited dynamic range which imaging sensors have. For this reason, various contrast enhancement methods have been proposed. The proposed method can enhance the contrast of images without over-enhancement and noise amplification. In the proposed method, a shadow-up function is used for preventing over-enhancement. In addition, a mapping function designed by using a noise aware histogram allows not only to enhance contrast of dark region, but also to avoid amplifying noise.**

I. INTRODUCTION

Various contrast enhancement methods have been proposed, to improve the qualities of images [1]- [7]. The histogram equalization (HE) [1] is one of the most popular algorithms for contrast enhancement and there are various extended versions of the HE [2]. However, these histogram-based methods generally cause the loss of details in bright regions due to over-enhancement of contrast. In addition, most of conventional methods amplify noise in dark regions because they do not consider noise included images. On the other hand, contrast enhancement methods based on the retinex theory have also been studied [3]. Although these methods can enhance the contrast while preserving details in bright areas, they also cause the noise amplifying as with histogram-based methods.

To avoid the noise amplification, some histogram-based contrast enhancement methods have been proposed. Low light image enhancement based on two-step noise suppression (LLIE) [4] uses both noise level function (NLF) and just noticeable difference (JND) in contrast enhancement for noise suppression. Although this method can reduce some noise, it does not preserve the details in bright areas as with other histogram-based methods.

Because of such a situation, this paper proposes a novel image contrast enhancement method based on a noise aware shadow-up function. The proposed method can enhance the contrast of images without over-enhancement and noise amplification. In the proposed method, a shadow-up function is used for preventing over-enhancement and the loss of details in bright regions. In addition, a mapping function designed by using a noise aware histogram allows not only to enhance contrast of dark region, but also to avoid amplifying noise.

Experimental results showed that the proposed method can produce high quality images without over-enhancement, and the proposed method outperforms conventional ones in terms of the noise robustness.

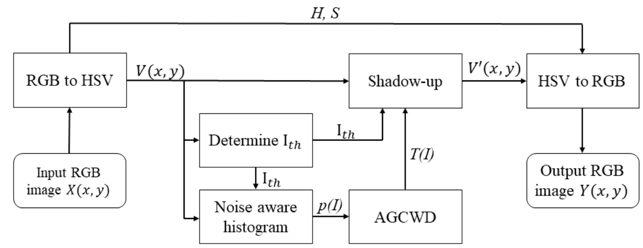
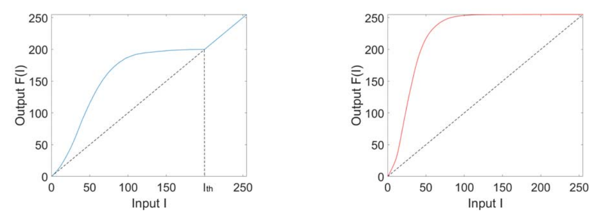


Fig 1. Flowchart of the proposed method.



(a) Proposed method with shadow-up function.

(b) AGCWD without shadow-up function.

Fig 2. Examples of mapping curves.

II. PROPOSED METHOD

The outline of the proposed method is shown in Fig. 1.

A. Shadow-up function

To avoid the loss of details in bright areas due to over-enhancement, a shadow-up function is used for contrast enhancement. The function, which consists of a nonlinear part and a linear part as shown in Fig. 2, is given by

$$f(I) = \begin{cases} T(I), & if\ I < I_{th} \\ I, & Otherwize \end{cases}, \quad (1)$$

where $I \epsilon [0,255]$ is the intensity of luminance V, $T(I)$ is a monotonically increasing function, and I_{th} is the upper limit for the nonlinear part. By using (1), the contrast of I is enhanced when I is less than a threshold value I_{th}.

B. Determining I_{th}

To determine a proper threshold value I_{th} for input image, we take into account the luminance distribution of the image. Let $H = \{(x, y): l_{th} < l(x, y) < l_{max}\}$, where l_{th} is the th percentile of luminance $l(x, y)$ of the input image, and l_{max} is the maximum of $l(x, y)$. The threshold value I_{th} is calculated as follows:

$$I_{th} = 255 - \frac{1}{|H|} \sum_{(x,y)\epsilon H} l(x, y), \quad (2)$$

The threshold value I_{th} becomes smaller for a brighter image, while I_{th} becomes larger for a darker image.

C. Determining $T(I)$ via noise aware histogram

Function $T(I)$ can be designed by using one of conventional methods. In the conventional methods, adaptive gamma correction with weighting distribution (AGCWD) [2] provides high quality images and it has a low computational cost. For this reason, we adopt AGCWD for determining $T(I)$. However, AGCWD usually causes the noise amplification because it does not consider noise characteristics. To overcome the problem, noise aware histograms are applied to AGCWD in this paper.

We compute the noise aware histogram of pixels as follows:

$$p(I) = \frac{|B_I|}{|S|}, \tag{3}$$

where

$$S = \{(x, y): c(x, y) > n(l(x, y)); l(x, y) < I_{th}\}, \tag{4}$$

$$B_I = \{(x, y) \in S: l(x, y) = I\}. \tag{5}$$

S is the set of pixels having higher contrast than the noise level, B_I is the subset of S which contains the pixels whose intensity is I. $c(x, y)$ is a local contrast estimated by using a Gaussian filter [8]. $n(l(x, y))$ is the model of noise level [9].

D. Proposed procedure

The proposed procedure for enhancing an image is summarized as follows (see Fig. 1).

1. Calculate value *V (x, y)* from an input image *X (x, y)*.
2. Determine a threshold value I_{th} by (2).
3. Calculate a noise aware histogram *p(I)* by using (3).
4. Design *T(I)* by using AGCWD [2] and I_{th}.
5. Calculate the enhanced luminance *V' (x, y)* according to (1).
6. Obtain the enhanced image *Y (x, y)* by transforming *H, S*, and *V' (x, y)* into the RGB color space.

III. SIMULATION

A. Simulation condition

We carried out two simulations, called Simulation 1 and Simulation 2, to compare the proposed method with state-of-art contrast enhancement methods, AGCWD [2] and LLIE [4]. The simulations were run on a PC with Intel i7 CPU (3.40GHz) and 8.00GB RAM running a MATLAB 2016b. We used four images, i.e. *Gallery, Campus, Water* and *Toy*, taken by camera SONY α7 II for the simulations. We adopted the 88th percentile as l_{th} because it outperformed the cases of *th=12, 25, 50,* and *75*.

B. Simulation results

1) Simulation 1 (Visual comparison)

In Simulation 1, the above-mentioned images, i.e. original ones, were used as input image *X* of each method. Next, we compared the resulting images, subjectively. Figure 3 illustrates input image *Campus* and the enhanced ones produced by each method. From Fig. 3(b), it is confirmed that AGCWD clearly reproduces dark areas with detail and over-emphasizes bright areas. Besides, while LLIE successfully reduces noise, some edges are lost. The proposed method dose not enhance bright area, so we can see the clear burst/sun star, and slightly enhance in sky and grass.

2) Simulation 2 (Noise robustness)

To evaluate noise robustness against each enhancement

TABLE I. PSNR value comparison for noisy images.

Methods	*Gallery*	*Campus*	*Water*	*Toy*	Avg. [dB]
AGCWD [3]	23.43	15.96	18.26	34.02	22.92
LLIE [4]	**29.75**	19.18	20.38	17.60	21.73
Proposed	25.54	**23.04**	**22.51**	**34.78**	**26.47**

(a)Original (b)AGCWD [2] (c)LLIE [4] (d)Proposed

Fig. 3. Experimental Results under different contrast enhancement methods.

method, noisy images were generated by adding Gaussian noise to the original one shown in Fig. 3(a). The mean and variance of the noise were zero and 0.005, respectively. Peak Signal-to-Noise Ratio (PSNR) values between enhanced images without any noise and enhanced noisy ones. Larger PSNR values indicate less affects due to the noise. Table I shows the objective evaluation results. The proposed method was better than AGCWD and LLIE on the average. The proposed method can be applied to a variety of different scenarios.

IV. CONCLUSION

In this paper, we have proposed a novel image contrast enhancement method based on a noise aware shadow-up function. The proposed method can enhance image contrast without over-enhancement and noise amplification. To prevent over-enhancement, the proposed method utilizes a shadow-up function. In addition, the use of noise aware histogram enables us to avoid amplifying noise. Experiment results showed that the proposed method successfully enhances contrast while preserving details of highlight regions and suppressing some noise in dark regions.

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