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Multi-scale retinex improvement for nighttime image enhancement[☆]

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ABSTRACT

We propose a retinex improvement for nighttime image enhancement. Retinex is often used on images under non-uniform illumination in terms of either color or lightness and has satisfactory results to achieve color constancy and dynamic range compression. Few studies focus retinex on nighttime images, especially those under extreme conditions (i.e., images with over-lighted or extremely under-lighted areas or with noise speckles), on which retinex operation can perform badly. Original multi-scale retinex (MSR) is extremely sensitive to noise speckles that cameras produce in low light areas, and it has unsatisfactory effect on areas with normal or intensive illumination. Moreover, original MSR uses a gain-offset method for prior-to-display treatment and can lead to apparent data loss on nighttime images. This paper replaces the logarithm function in MSR with a customized sigmoid function to minimize data loss, and adapts MSR to nighttime images by merging results from sigmoid-MSR with original images. Experiments show our framework, when applied to nighttime images, can preserve areas with normal or intensive lighting and suppress noise speckles in extreme low light areas.

1. Introduction

Nighttime image enhancement is a particular problem of those dealing with images with variant lighting conditions. Retinex, is one effective theory aiming at simulating Human Visual System (HVS) to achieve color constancy and dynamic range compression. This paper shows that with modifications, retinex can be applicable to nighttime images even under extreme conditions. In 1986, Edwin Land [1] proposed the last version of his retinex theory as a model for human color constancy. Later, several works emerged implementing this retinex theory but with huge computational cost and sometimes low performance in some extreme cases. What caught our attention is the center/surround retinex, which was also brought up by Edwin Land [2] and has the characteristics of easy implementation, fast computation and less parameters. Research from NASA [3,4] further improved this c/s retinex leading to what is called single-scale retinex (SSR) and multi-scale retinex (MSR), which is shown to be able to accomplish color rendition and dynamic range compression at the same time.

Recent research focus on retinex, especially on multi-scale retinex, recedes a bit and only a few works stand out. Work from Jang [5,6] focuses on better color correction for retinex algorithm. Robinson et al. [7] improve MSR by reducing halo artifacts and graying effect. Rahman et al. [8] investigate the relationship between retinex and image compression. Jang [9] improves the MSR with respect to weights of different scales of retinex. And papers [10,11] both propose to accelerate the implementation of MSR.

Through experiments, we see that MSR can have overall acceptable results on nighttime images. It consistently provides color constancy, dynamic range compression and in short, better visual quality. However, one of their post-processing algorithms has to be reconsidered. Due to the logarithm function in c/s retinex and SSR or MSR, the primary results of these retinex processes can have large range of value and are impossible to be displayed as images directly. One approach we now commonly use is proposed in [3] involving a gain-offset method which clips those pixels with too high or too low lightness, in which case, it is shown little information is lost. However, as for nighttime images where extreme high light and low light pixels are of common occurrence, critical information may lose resulting in apparent artifacts.

This is where sigmoid function comes in. Our intuitive idea is to eliminate the uncertainty of the value range of the result from the beginning, where we used to take the logarithm of the ratio between two intensity values. This ratio ranges from 1/256 to 256

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and the logarithm of the ratio makes itself distribute loosely across its range. We set the higher and lower threshold of the gain-offset method empirically. However, considering the extreme conditions in nighttime images, the gain-offset method is not satisfactory. In originally processed nighttime images, too many pixels' lightness exceeds those thresholds. However, to maintain the natural lightness and color of a image, shifting these thresholds is not an option.

So we came up with an idea to replace the logarithm function with the sigmoid function, which has a certain range of output. This certainty is obtained by compressing the 'extreme' pixels rather than clipping them. So unlike the logarithm method, it does not need the gain-offset method which involves clipping and leads to information loss. Combined with other methods discriminating between areas of different illumination, our framework has overall better enhancement effect among nighttime images.

In the following section, we first introduce the well known MSR. Next, Section 3 introduces our proposed method, including the aforesaid sigmoid function and methods to suppress noise and preserve high-light details. Section 4 presents the experiment results to show the improvements.

2. Original MSR

The retinex theory was brought up by Edwin Land [1] to simulate Human Visual System which, when capturing images, is surprisingly good at adapting to variation of lighting condition, compared to how nowadays cameras perform. This paper mainly bases itself on one of retinex's successful formulation from Rahman's work [4]. Its MSR proves to be able to achieve dynamic range compression on daytime images suffering from uneven lighting condition. Nighttime images share the same characteristics but behave more extremely.

The Original MSR [4] can be written as

$$F_i(x, y) = \sum_{n=1}^{N} W_n \cdot \{\log[S_i(x, y)] - \log[S_i(x, y) * M_n(x, y)]\} \tag{1}$$

where F is the result we get from MSR operation, the subscripts $i \in R, G, B$ indicate the 3 color channels, N is the number of scales of retinex computed, and W_n are the weighting factors of each scale. $S_i(x, y)$ is the ith channel 2-dimensional matrix of the input image, mark $*$ is the convolution operator, and the $M_n(x, y)$ are the surround functions given by

$$M_n(x, y) = K_n \exp\left[\frac{-(x^2 + y^2)}{\sigma_n^2}\right] \tag{2}$$

where K_n is to insure $\int\int M_n(x, y)\mathrm{d}x\mathrm{d}y = 1$. Each of the expressions within the summation in Eq. (1) represents an SSR. This expression of SSR can also be written as

$$\log\left[\frac{S_i(x, y)}{S_i(x, y) * M_n(x, y)}\right] \tag{3}$$

which can be intuitively perceived as a comparison between the current pixel and its weighted, surrounding pixels. σ_n are the standard deviations of the gaussian distribution determining the scales of the surrounding neighborhood taken into account. Smaller scales provide more dynamic range compression, and larger ones provide more color constancy.

After the initial retinex process accomplished by Eq. (1), it is shown that among various scenes, there's a characteristic form for the resulting histogram (Fig. 1).

Regardless the various scenes, the data is distributed around zero and has a form of a gaussian distribution. A usual approach to display the result as an image is to clip both the highest and lowest data and use gain-offset method to produce the final image.

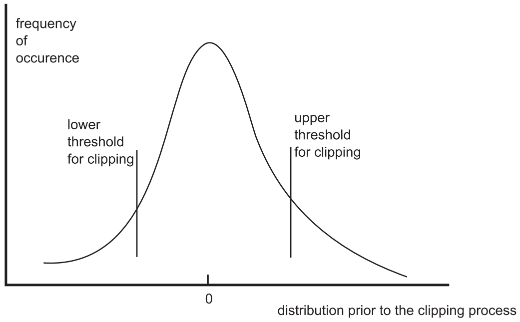

Fig. 1. The clipping method after initial retinex operation illustrated on histogram.

The higher and lower threshold for this clipping step can be determined by

$$T_H = M + \alpha \cdot d \tag{4}$$

$$T_L = M - \alpha \cdot d \tag{5}$$

where M and d is the average lightness and standard deviation of the whole image, respectively. α is a factor determining how much variation of the lightness to keep. Large α keeps more lightness information but has poor visual effect, since the lightness distribution will be closely around the average value and little lightness variation can be perceived. Small α will lead to better lightness distribution but also greater information loss since it has lower T_H and higher T_L. So it's basically a trade-off between more information for highlight/lowlight pixels and more nature visual effect.

3. Proposed method

When directly used on nighttime images, the original MSR may manifest the following defects:

(1) The clipping method prior to display can lead to data loss especially in areas highlighted or non-lighted. This kind of areas are very common in nighttime images unlike those took in normal daytime (See Section 4 for details).
(2) Retinex's nature tends to magnify the lightness difference between pixels to improve clarity, which, in nighttime images where noise is quite common, can significantly increase the noise effect.

What we propose is firstly to replace the logarithm function with a customized sigmoid function, which is intended to act as the logarithm one except that it's nicely bounded and only to compress the lightness close to its bound. Thus no clipping is needed and no apparent data loss is incurred. It is a monotonic increasing function and its form can be easily manipulated, i.e., the upper bound and the lower bound and the derivative at a certain point. Secondly, based on the cause of the magnified noise effect, we implemented a simple method to suppress the noise. Finally we apply a similar method to also preserve areas with good illumination.

3.1. Sigmoid function

A simple form for a sigmoid function is

$$\mathrm{Sig}(x) = \frac{1}{1 + \mathrm{e}^{-x}} \tag{6}$$

and the corresponding shape is shown in Fig. 2.

The function is bounded and is monotonically increasing like logarithm. It needs to be modified so that it has the output range between 0 and 1, appropriate derivative and function value when $x = 1$, and a similar form to the logarithm function.