# Night Time Image Enhancement by Improved Nonlinear Model

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**Abstract.** Low light or poor shooting angle and other issues often make the camera to take night time images and affect the naked-eye observation or computer identification, so it is important to enhance the lightness of night time image. Although the existing non-linear luminance enhancement method can improve the brightness of the low light area, the excessive promotion led to high light area distortion. Based on the existing image luminance processing algorithm, we proposed an adaptive night time image improving method in the basis of nonlinear brightness enhancement model is proposed to process the segmentations of image brightness by using the logarithmic function. The segmentation threshold is determined by the Otsu, and the adjustment factor of the backlight region in the transfer function is calculated from the area ratio of the backlight area. The conclusion comes from the simulation. The method involves improving the image quality and ensuring that the entire picture is natural without distortion. In the meanwhile, the processing speed is not much slower compared with the existing processing algorithms.

**Keywords:** Night time images · Brightness · Adaptive Nonlinearity Model Otsu Threshold

## 1 Introduction

The camera adjusts the degree of sensitivity through the sensor chip. Therefore, when the camera lens is shooting in front of the light source, the sensor chip to detect the subject of the reflected light is weak and its sensitive to the surrounding light source reflects the light is strong. After imaging, the main body of the image brightness is low and the same as ambient brightness under the night condition. It is difficult to obtain the effective information from the picture and affect the extraction of information. The four pictures in Fig. 1 are photographed in the night low light environment. There is a significant darkness in brightness in the picture. The main area brightness is too low to affect identification of the details information. Therefore, it is necessary to restore the night image.

The enhancement of night images should be conducive to visual observation and accurate identification of the computer. We need to enhance the brightness of the


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(a) night school yard image

(b) night road image

(c) night building image

(d) night people image

**Fig. 1.** Low light night-time image

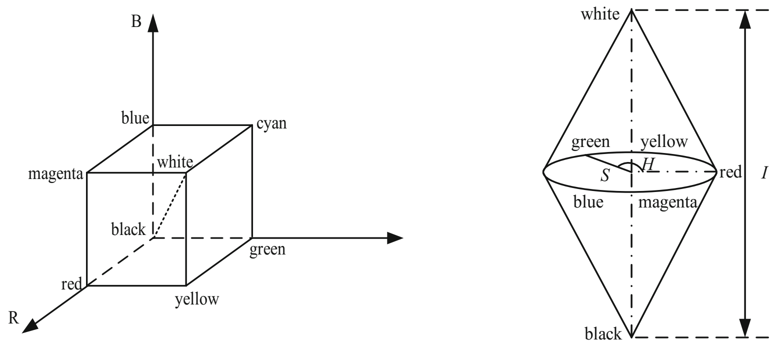
low-light area of the night image and try to keep the brightness of the high-brightness area unchanged. The picture should not be distorted after restoration.

In the image processing area, many researchers have been explored the methods to change the image brightness. In [4], the traffic image is adjusted according to the time variation, which is convenient for vehicle detection and license plate recognition. In [5], the relationship between the histogram and the brightness is explored and it is found that the histogram of the image brightness suitable for human eye observation should be evenly distributed. In [6], brightness adjustment is achieved from the histogram of the equalization. In [7, 8], the image is adjusted by brightness and wavelet transformation. The brightness of the original image is changed by the wavelet transformation so that to improve the readability of the image. In [9], the color image is enhanced by the non-linear Retinex illumination reflection model, which improves the local contrast of the image. In [10], a method of uneven brightness images based on theory of homomorphic filtering is proposed. This method suppresses the low frequency component and enhances the high frequency component. In [11], the brightness of the backlit image is segmented linearly processed, and it is proved that the brightness processed in the HSI space is more effective than in the histogram equalization method, the homomorphic filtering and the retinex theory. In [12], using the logarithmic function in the HSI space model to adjust the brightness of the image, which improves the image quality. In [13], utilize the adaptive Gamma Correction model is used to adjust the image brightness in the HSI space model to improve the contrast. In [14], the power function of different parameters is used to adjust the brightness in the HSI space model to improve the influence of illumination unevenness on the image information acquisition.

Generally speaking, the enhancement of night images should be conducive to the rapid observation of the naked eye and the computer. Based on the literature [11–14], we choose to process the brightness in the spatial domain.

## 2 Prior Adjustment Model

The color of image pixels can be represented by a vector in the RGB color space, as shown in Fig. 2(a), it can also be represented by a vector in the HSI color space, as shown in Fig. 2(b). In the HSI color space, H represents the hue, S is saturation and I means the intensity. The night time condition is strongly affect the brightness of the image, while smaller influence on the shade of the image. At the same time, the luminance component we has nothing to do with the color information of the image and can be dealt with individually in the HSI model, so we choose to process the image in the HSI model.




(a) RGB color space (b) HSI color space

**Fig. 2.** Color space representation

The formula for converting each pixel color from RGB to HSI model in the image is:

$$H = \begin{cases} \theta & B \leq G \\ 360 - \theta & B > G \end{cases} \tag{1}$$

$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)] \tag{2}$$

$$I = \frac{1}{3}(R+G+B) \tag{3}$$

Hypothesis that the values of R, G, and B are normalized to the interval [0, 1], then the values of S and I are [0, 1], the value of H is [0, 360], and the values of $\theta$ are:

$$\theta = \arccos \frac{\frac{1}{2}[(R-G)+(R-B)]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \tag{4}$$

The transformation makes the luminance component, we can be carried out separately in the subsequent algorithm processing, which greatly simplifies the computation. In the low light image, assume that the luminance of the pixel normalized at the coordinates $(x, y)$ is $f_n(x, y)$, and the adjusted luminance is $g_n(x, y)$. The values of $f_n(x, y)$, $g_n(x, y)$ are [0, 1] (the larger the value represents the higher the brightness). The low light recovery process can be regarded as passing the normalized image luminance $f_n(x, y)$ through a transformation function $T_r$, which is:

$$g_n(x,y) = Tr[f_n(x,y)] \tag{5}$$

In order to facilitate the narrative, in the night image that needs to be enhanced, we refer to the region with low brightness under the low light condition, which is called the dark region, and the region with high brightness under the condition of strong light source is called well-light region. To restore the night image, the brightness of the dark area needs to be increased and the brightness of the original well-light area stays stable.

## 2.1 Piecewise Linear Regulation

The relationship between the brightness of piecewise linear adjustment is:

$$g(x,y) = \begin{cases} k_1 \times f_n(x,y) + b_1 & f_n(x,y) \le \tau \\ k_2 \times f_n(x,y) + b_2 & f_n(x,y) > \tau \end{cases} \tag{6}$$

Result of brightness adjustment can be changed by modified values of $k_1$, $k_2$, $b_1$, $b_2$ and $\tau$ in the equation. When $k_1 = 8/3$, $k_2 = 2/7$, $b_1 = 0$, $b_2 = 5/7$, $\tau = 0.3$, the recovery results are shown in the following figure.


(a) Original night-time image (b) Results of linear adjustment (c) Processing function image

**Fig. 3.** Comparison of piecewise linear adjustment results

It can be concluded from Fig. 3 that the segmented model improves the dark portion, but the processing is ineffective and the distortion of the junction is present. Distortion is caused by the non-smoothness of the function segment. If you want to get better processing in the dark part, the brightness of non-backlight part will rise rapidly, it will also cause distortion. It is clear that the processing of the night image by the piecewise linear model does not fully meet the demand of people.

### 2.2 Logarithmic Regulation

Literature [12, 14] adopted logarithmic function and power functions with different parameters to adjust brightness. Based on the requirements for backlighting image brightness processing, the logarithmic function [12] is used to improve the adjustment to the high-brightness area, the equation is:

$$g_n(x, y) = C \times \log_2[D \times f_n(x, y) + 1] \tag{7}$$

Taking D as the adjustment coefficient, it is used to change the brightness of transformation function to improve performance. The value of C is as follows:

$$C = \frac{1}{\log_2(D + 1)} \tag{8}$$

Choosing D = 20, the result of backlight processing on Fig. 1(a) is shown in Fig. 4. Even though this result is much better than the one of linear regulation, there are still distortion existed in high-brightness area.


(a) Original night-time image (b) Results of non-linear adjustment (c) Processing function image

**Fig. 4.** Comparison of piecewise non-linear adjustment results

## 3 Improved Nonlinear Enhancement Model

Processing of well-light area is not ideal, even though logarithmic enhancement adjustment model can improve dark area well. So we proposed an adaptively piecewise method by power function, instead of logarithmic function, which would adjust brightness of dark area rapidly and slowly in well-light area. Adjustment formula is,

$$g_n(x,y) = C_i \cdot f_n(x,y)^{\frac{1}{a}} \tag{9}$$

where, $a$ is a constant.

Night time image has very low light in dark place, after transfer to gray image, the luminance of most pixel centered on 0–30. According to Fig. 5, Power function can rise the brightness rapidly in low light area than other function. Inversely, in well-luminance area, adjustment function should be serial and convergent gradually, then selected apposite adjustment coefficient to improve brightness.

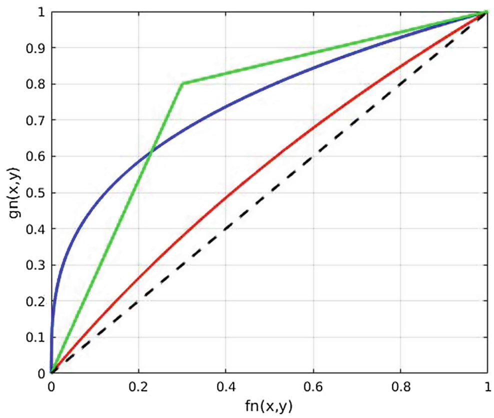



**Fig. 5.** Three adjustment functions. The blue is power function, the red is logarithmic function and the green is piecewise linear function. It shows the gradient of power function is the largest when $f_n(x,y)$ range from 0 to 0.2, and rises slowly during 0.3 to 1.0. (Color figure online)

### 3.1 Threshold Selection

We divide the luminance in two parts, threshold T belongs 0 to 1, and define that $f_n(x, y) \leq T$ is low light area, and $f_n(x, y) \geq T$ is high light area. The Selection of T can distinguish the low light area and high light area effectively. So we decided computing T by Otsu Threshold Algorithm, steps as follows: Setting night time image has $M \times N$ pixels, $\{0, 1/L, 2/L, \ldots, (L-1)/L\}$ means that levels of luminance are L, $n_i$ represents the number of pixels in i lightness, therefore title pixel numbers of night time image is $MN = n_0 + n_1 + \ldots + n_{L-1}$. Hypothesis threshold T $(0 < T < (L-1)/L)$ classifies lightness of image into two parts, low luminance area $C_1$ and high luminance area $C_2$, $p_i = n_i/MN$ is the percentage of pixels with lightness level i. Then threshold T can get the maximum of $\sigma_B^2$, which is the variance in different parts.

$$\sigma_B^2(T) = \frac{[m_I P_1(T) - m(T)]^2}{P_1(T)[1 - P_1(T)]} \tag{10}$$

In (10), $P_1(T)$ is the probability that pixels can be divided into $C_1$, m(T) represents accumulative mean value to level T, $m_I$ means the average luminance of the whole image.

$$P_1(T) = \sum_{i=0}^{T} p_i \tag{11}$$

$$m(T) = \sum_{i=0}^{T} ip_i \tag{12}$$

$$m_I = \sum_{i=0}^{L-1} ip_i \tag{13}$$

### 3.2 Coefficient Selection

When adjustment by logarithmic function, it just partly be enhanced if D is appointed a random positive constant, and not effective to the image take by dark place. There is still a large space for lightness improving unexpected, when $f_n(x, y)$ is larger. So we proposed a new piecewise function based on nonlinear power function. $g_n(x, y)$ is defined as:

$$g_n(x,y) = \begin{cases} C_1 \times f_n(x,y)^{\frac{1}{D_1}} & 0 \le f_n(x,y) \le T \\ C_2 \times f_n(x,y)^{\frac{1}{D2}} + A & T \le f_n(x,y) \le 1 \end{cases} \tag{14}$$

$$C_i = \begin{cases} 1 & i = 1 \\ 1 - A & i = 2 \end{cases} \tag{15}$$

There, threshold T will be achieved by computing Ostus threshold segment method. $D_i$ is the adjustment coefficient in i section (i = 1, 2). When $f_n(x,y) \le T$, select $D_1$ as adjustment coefficient; $f_n(x,y) \le T$, $D_2$ is better. We expected an adjustment coefficient that $D_i$ is a serial function of $f_n(x, y)$, if $f_n(x,y) \le T$, $D_1$ is large; if $f_n(x,y) \le T$, $D_2$ will be smaller gradually, and the transfer function will converge to $g_n(x, y) = f_n(x, y)$. In other words, high light area would keep its luminance or be improved little. Follow the requirements, formula of $D_i$ is:

$$D_i = \begin{cases} C \times A & f_n(x,y) \le T \\ \frac{1}{\lg_T[(C_1 T^{(1/CA)} - A)/C_2]} & f_n(x,y) \ge T \end{cases} \tag{16}$$

A is a positive real, when A is larger, the luminance of $f_n(x,y) \le T$ improved higher. According to experiments, A is not the larger the better. If it’s too large, will result in the lightness of low light area improved excessively and artifacts. We hope that when the area of low light region bigger than high light, the luminance of

$f_n(x,y) \leq T$ rises more; the area of low light region smaller than high light, the luminance of $f_n(x,y) \leq T$ rises little. So we select A as:

$$A = k \times \sqrt{\frac{n_{[f_n(x,y) \leq T]}}{MN}} \tag{17}$$

where k is a positive constant, and $n_{[f_n(x,y) \leq T]}$ stands for pixel numbers when $f_n(x,y) \leq T$.

### 3.3 Compute Procedure

Base on the theory before, the processing of enhancing night-time image lightness summarized in Table 1.

**Table 1.** Processing of luminance enhancement

| ***Algorithm1*** Process of enhancement |
|---|
| 1. Read original night-time image I; |
| 2. Statistic the pixel width and height of image I; |
| 3. Transfer I from RGB space to HSI space; |
| 4. Compute threshold T and ratio A; |
| 5. Select adjust coefficient $D_i$; |
| 6. Adjust the lightness according to the transfer relationship; |
| 7. Achieve the enhancement image I'. |

## 4 Result and Discussion

### 4.1 Enhancement Result

This paper proposes improved algorithm on a computer of memory of 8G (model for DDR RME510H38C6T-400), frequency of 3.4 GHz and 64 bit Linux operating system, simulating and calculating the original night image in Fig. 6(a)–(d) to get the result through process of 2.3. The recovered images with improved nonlinear adjustment method of this paper are illustrated in Fig. 6(a')–(d'). Get the Fig. 6(a'')–(d'') compared with the proposed method of [12].

We can effectively enhance the original image brightness in the dark part of the details with the method described in this article, and the improved adjustment method of this paper changes less on the well-light part and causes no distortion in compared with the traditional method of nonlinear inverse processing method described in this article. In Fig. 6, compare with the results of [12], ours can enhance the brightness obviously and successfully avoid distortion caused by excessive improvement. From Fig. 6(a) and (b), trees beside the street are difficult to identify because of lowlight condition, we can clearly recognize the details of the tree and the road in (a') and (b'). Our results keep luminance of the well-light area in (a) and (b), compared with (a'') and (b'') computed by [12],which light brightness is too high to cause distortion.


**Fig. 6.** Results of different algorithms

Two buildings details in (c) are hard to distinguish, power function algorithm can observe the texture of the wall and the stone in (c’). In the Fig. 6(c’’) which results of [12], the building’s top is too bright and little details left. Cars and trees in Fig. 6(d) are difficult to distinguish because of darkness, our method recover the details of cars and trees in Fig. 6(d’). Especially we can restore the information of the sky, but (d’’) only provide the shape of the car in front of the image.

### 4.2 Judgment Criteria

The steps of processing are measured in length in the experiment environment described in Sect. 3.1, and the intensity of the image normalization is calculated to get Tables 2 and 3.

We find that the running time of the program is related to the size of the image, namely pixel value (M × N). The larger M × N, the longer processing time. The improved method will slow the traditional method of [12] on the processing speed,

**Table 2.** Statistic time of processing.

| Pic | Pixel num | Time of us (s) | Time of [12] (s) |
|---|---|---|---|
| (a) | 442 * 299 | 4.465262 | 3.307465 |
| (b) | 1148 * 858 | 13.44732 | 3.442836 |
| (c) | 700 * 465 | 4.223594 | 3.352265 |
| (d) | 690 * 388 | 8.889232 | 3.418154 |

which is mainly due to the improvement to piecewise nonlinear adjustment of brightness, rather than the whole nonlinear adjustment, but in general, the improved method has higher operation efficiency and satisfactory processing speed, which mainly depends on that this paper only uses the I component of HSI model for low light processing, rather than the three color components of the RGB model.

Make new statistics of brightness, and compared to the number of pixels before, Table 3 shows the result.

**Table 3.** Comparison of luminance threshold after processing and before.

| Normalization luminance | 0–0.3 | 0.3–0.7 | 0.7–1 | Numbers of total pixel |
|---|---|---|---|---|
| (a) Original night image | 0.9013 | 0 | 0.0987 | 422 * 299 |
| (a') Ours | 0.3824 | 0.5289 | 0.0887 | |
| (b) Original night image | 0.9915 | 0 | 0.0085 | 1148 * 858 |
| (b') Ours | 0.0091 | 0.98 | 0.0109 | |
| (c) Original night image | 0.9538 | 0 | 0.0462 | 700 * 465 |
| (c') Ours | 0.7271 | 0.2063 | 0.0666 | |
| (d) Original night image | 0.9964 | 0 | 0.0036 | 690 * 388 |
| (d') Ours | 0.8554 | 0.1184 | 0.0262 | |

From the above table, the paper can be concluded that there is a widespread phenomenon in the original night image: there is a huge difference between the brightness of the background and the main part. The background is mainly in high brightness (0.7–1) and the main part mainly in the low light (0–0.3). There is basically no pixels in the range of 0.3–0.7. Backlight processing mainly transfers the pixels of the lower area to middle brightness area by nonlinear transformation, which can be proved from the processed data. Table 2 shows that proportion of pixels with the improved method is closer to the original image than traditional methods in the range of 0.7–1. The improved method mainly adjusts the image pixel brightness by transferring the 0–0.3 area to the 0.3–0.7 area, and high brightness area (0.7–1) changes little, meanwhile the traditional method of [12] changes a lot in the high brightness area. In addition, the more even the brightness distribution is, the broader, the better the quality of the image is in theory, which can also be found from data processing. The processing of this paper is conducive to a better resolution.

## 5 Conclusion

In order to improve the night image to make it better for naked eye and computer identification, an improved method for nonlinear brightness improving model is put forward in this paper. Get segmentation threshold T with Otsu threshold segmentation method and the well-light area brightness improving coefficient by calculating the ratio of backlighting area to total pixels. Improve brightness of night image by piecewise method. The enhanced image can clearly get the details of the original dark area after processing.

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