Low-illumination image enhancement algorithm based on multi-feature fusion

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Abstract. In order to improve the effect of image acquisition under the condition of low illumination, a low illumination image enhancement algorithm based on multi-feature fusion is adopted in this paper. In this algorithm, the illumination information is extracted by bilateral filtering, and the illumination parameters are processed by adaptive gamma correction and limited contrast histogram equalization algorithm. The final illumination parameters are obtained by the feature weighted fusion of the processed parameters and the original illumination parameters. The RGB image is obtained by combining the illumination and reflection parameters, and the enhancement of the image is realized. The experimental results show that the algorithm used in this paper can not only improve the brightness of the image, but also enhance the characteristic parameters of the image, remove the noise, and make the color information of the image fuller and richer

1. Introduction

Under the condition of low illumination at night, the poor lighting conditions of the surrounding environment and the problems of the image acquisition equipment will affect the quality of the image acquisition. As a result, the gray value and contrast of the whole image are low and the region of interest is difficult to identify. In addition, a part of the image has low gray value due to the lack of light or located in the shadow area, which is fused with the background, making it difficult to extract the information of this part of the original image. Therefore, enhancing the brightness and contrast of low illumination image has important application value. There have been many methods to solve the problem of low illumination image enhancement, such as histogram equalization algorithm, Retinex algorithm, MSRCR algorithm, spatial color image enhancement algorithm[1], gradient image enhancement algorithm[2], bionic color image enhancement algorithm[3], homomorphic filtering algorithm based on illumination reflection model[4], HDR algorithm, etc. Histogram equalization algorithm has a particularly good enhancement effect on images with an overall darker or brighter image, it has been widely used in image enhancement. But for low illumination image, it is easy to over enhancement [5-6]. In order to solve this kind of problem, histogram equalization algorithm of keeping brightness mean value and adaptive histogram equalization algorithm with limited contrast are proposed. The two algorithms can restrain over-enhancement phenomenon in the process of enhancement, but can not enhance the image’s detail and brightness at the same time [7-8]. Detailed
information of dark area of image is lost [9-10]. Wavelet algorithms can enhance image components in different frequency ranges, highlight details in different scales, but the amount of calculation is too large, which is easy to amplify noise [11]. To solve this kind of problem, people proposed the method of combining wavelet with curved wave and the algorithm based on DWT and SVD. Although the noise is removed, the complexity of the algorithm is increased [12]. Retinex algorithm and its derivative algorithm decompose the image into illumination component and reflection component, and then process them. However, this kind of algorithm has a large amount of computation, which is easy to produce halo phenomenon [13]. For this reason, people put forward the Retinex image enhancement algorithm based on gyrosymmetric bilateral filtering algorithm and Markov random field. Although this kind of algorithm avoids halo phenomenon, the noise is not removed, which will produce over enhancement and under enhancement phenomenon. In reference [14], a Retinex algorithm based on bilateral filtering is proposed. This algorithm can remove the "halo" phenomenon and image noise well, and has good visual effect. However, the enhanced image detail information is not clear enough, and the image contrast is also low. Although the enhancement effect of image fusion algorithm is good, it needs to capture multiple images continuously, which is difficult to meet the real-time demand. To solve this problem, literature [15] proposed a weak light image enhancement algorithm of single image fusion, which can enhance the detail information of the image and improve the contrast of the image, but the real-time performance of the algorithm is not good, and the details of the dark area will be lost. Based on this, this paper adopts a low illumination image enhancement algorithm based on multi-feature fusion.

2. Low illumination image enhancement algorithm based on multi-feature fusion

2.1. Algorithm implementation

Based on the light reflection model, this paper combines the contrast enhancement and detail enhancement of low illumination image, and proposes a low illumination image enhancement algorithm based on multi-feature weighted fusion. The algorithm implementation flow is shown in Figure 1.

![Algorithm Flow Diagram](image)

**Figure 1. Algorithm flow**

2.2. Light component processing

In order to improve the image quality of low illuminance image and reduce the influence of illumination on image, it is very important to extract the illumination information of image accurately. At present, there are many algorithms for extracting illumination information, such as Gauss filtering algorithm, bilateral filtering algorithm and Retinex algorithm of variational frame. Retinex algorithm based on variational frame is used to extract illumination information. In this paper, a bilateral filtering algorithm with edge preserving feature is used to extract the illumination information of the image, which can keep the edge information of the image well and restrain the image noise at the same time. Set A1 is the original light component of the low illumination image. A2 is the result of light component correction by adaptive gamma correction in this paper. The main purpose is to improve the image brightness. Firstly, the parameter \( g \) is obtained adaptively by using the mean value of estimated
light component $A(x, y)$, and then the parameter of gamma correction $G(x, y)$ is adjusted adaptively. Namely

$$g = 1 - \frac{1}{m \times n} \sum_{x=1}^{m} \sum_{y=1}^{n} A(x, y)$$

$$e(x, y) = \frac{(A(x, y) + g)}{1 + g}$$

$$A_p(x, y) = CLAHE(A(x, y))$$

Among them, $m$ and $n$ are the width and height of the image respectively, and $e(x, y)$ is the adaptive parameter of gamma correction based on the pixel information of the original light component. Then we use the contrast-limited adaptive histogram equalization (CLAHE) to process the light component, and get the A3 component.

According to the above three kinds of light components, this paper adopts a low illumination image fusion algorithm based on pixel level, and each pixel in the fusion image is the weighted average of the corresponding pixels in the three light components. The features of the pixels used can measure the quality of the image and the quality of the detail information. In this paper, the variance, gradient and entropy of the image can be used to reflect the quality of the image. In the experiment, for each pixel $(x, y)$, take a $(2d + 1) \times (2d + 1)$ square window with the pixel as the center, count the three image features in the window, and then determine the weight of the pixel in the fusion according to the local features of the region $p$ where the pixel is located. Finally, according to the pixel level fusion method, deduce the three light components of the image. In the algorithm, the formula is defined as follows:

$$R_{var}(x, y) = \frac{1}{f} \sum_{m-x-k}^{x+k} \sum_{n-y-k}^{y+k} [A_p(m, n) - \bar{A}_p]^2$$

$$R_{grad,p}(x, y) = \frac{1}{f} \sum_{m-x-k}^{x+k} \sum_{n-y-k}^{y+k} \{ |A_p(m+1, n+1) - A_p(m, n)| + |A_p(m, n+1) - A_p(m+1, n)| \}$$

$$R_{s,p}(x, y) = \sum_{m-x-k}^{x+k} \sum_{n-y-k}^{y+k} p(A_p(m, n)) \log 2 p(A_p(m, n))$$

$$\bar{A}_p = \frac{1}{f} \sum_{m-x-k}^{x+k} \sum_{n-y-k}^{y+k} A(m, n)$$

$$f = (2d+1) \times (2d+1)$$

Among them: $A_p$ is the $p$-th light component estimation, $R_{var,p}(x, y)$ is variance, $R_{grad,p}(x, y)$ is gradient and $R_{s,p}(x, y)$ is entropy.

Because the image quality evaluation is related to the above variance, gradient and entropy, the image quality concept is written as:

$$A_p(x, y) = L(\mu \theta(x, y), \nu \theta(x, y), \sigma \theta(x, y))$$

The value of $\mu$, $\nu$, $\sigma$ is 0 or 1.

Set the weight coefficients of the above three parameters are:

$$b_p(x, y) = \frac{A_p(x, y)}{\sum_{i=1}^{3} A_p(x, y) + \varepsilon}$$
Among them, $A_p(x, y)$ is the quality degree of light parameter estimation; the weight coefficient satisfies $\sum_{i=1}^{3} b_{i,p}(x, y) = 1$, $0 \leq b_p(x, y) \leq 1$. $\varepsilon$ is a very small positive real number, therefore, after fusion processing, the light components are as follows:

$$A_{\text{seg}}(x, y) = \sum_{p=1}^{3} b_p(x, y) \times A_p(x, y)$$ (12)

3. Experiment and analysis

In this paper, two kinds of low illuminance images of different scenes are selected for the experiment. As shown in the figure 2-3, a) is the Retinex algorithm, b) is the histogram equalization algorithm, c) is the MSRCR algorithm, d) is the spatial color image enhancement algorithm, e) is the gradient domain image enhancement algorithm, f) is wavelet transform algorithm, g) is the algorithm of this paper. And the 7 methods are used for processing images, then compared and analyzed the experimental results.

![Figure 2. Scenery images](image1)

![Figure 3. Pet images](image2)
As can be seen from Figure 2, a) algorithm and b) algorithm can increase the contrast and brightness while increasing the local details of the image, but the image as a whole will be over enhanced, resulting in the visual effect is not natural. After the image is enhanced by c) algorithm and f) algorithm, there is colour distortion. d) algorithm has halo. The results of this paper’s algorithm are more natural, no halo, and the image visual effect is more in line with the human visual characteristics. As can be seen from Figure 3, the enhancement effect of e) algorithm and f) algorithm is not obvious enough. e) algorithm in the low illumination area and the contour around the light source are not high, and the enhancement algorithm improved by the algorithm of this paper improves the image quality more obviously than other algorithms. This paper’s algorithm has full colour and histogram distribution is well-distribute.

In order to better evaluate the quality of panoramic image processed by different algorithms, the enhancement image is evaluated objectively from two aspects: clarity and the amount of information contained in the image. This paper selects the improved Brenner image sharpness evaluation algorithm to assess definition, which is very sensitive to image sharpness and proposed by literature[16]. The closer the index is to 1, the higher the image sharpness is, and vice versa. In terms of the information content of the evaluation image, this paper selects the information entropy as the evaluation index. The higher the information entropy is, the more information the image contains, and vice versa. The information entropy of the enhanced image corresponding to each algorithm and the image clarity proposed in literature [16] are shown in Table 1 and Table 2 respectively.

| Algorithm name                          | Fig.2 | Fig.3 |
|----------------------------------------|-------|-------|
| Original image                         | 5.23  | 6.04  |
| Retinex algorithm                      | 6.67  | 7.11  |
| Histogram equalization algorithm       | 6.43  | 7.18  |
| MSRCR algorithm                        | 6.01  | 6.57  |
| Spatial color image enhancement algorithm | 5.78  | 7.23  |
| Gradient domain image enhancement algorithm | 5.89  | 6.85  |
| Wavelet transform algorithm            | 5.58  | 6.78  |
| Algorithm in this paper                | 6.77  | 7.22  |

Table 2. Image definitions of relevant algorithms

| Algorithm name                                      | Fig.2 | Fig.3 |
|---------------------------------------------------|-------|-------|
| Original image                                     | 0.53  | 0.57  |
| Retinex algorithm                                  | 0.88  | 0.78  |
| Histogram equalization algorithm                   | 0.71  | 0.89  |
| MSRCR algorithm                                    | 0.71  | 0.71  |
| Spatial color image enhancement algorithm          | 0.78  | 0.91  |
| Gradient domain image enhancement algorithm        | 0.79  | 0.76  |
| Wavelet transform algorithm                        | 0.74  | 0.75  |
| This paper’s algorithm                             | 0.91  | 0.93  |

It can be seen from Table 1 and Table 2, compared with the original image, each image enhancement algorithm can improve the amount of information contained in the image. The clarity and entropy of the improved algorithm are higher than those of the traditional algorithm, which shows that the paper’s algorithm can effectively improve the image quality.

4. Conclusion
In order to solve the problem of low illuminance image enhancement, this paper proposes a low illuminance image enhancement algorithm based on multi-feature fusion. The experimental results
verify that the algorithm in this paper can not only obtain good enhancement effect, but also overcome the shortcomings of colour distortion, halo effect and low contrast in the process of enhancement, so that the overall brightness of the enhanced image is significantly improved, and the details are further highlighted and increased. The colour of the strong image is natural, which effectively improves the visual quality of low illuminance panoramic image. In the process of low illuminance image enhancement, noise often has a great impact on the image. Therefore, it is of great significance to research on the enhancement of low illuminance image by adding the denoising process to the low illuminance image enhancement algorithm to realize the combination of image denoising, contrast enhancement and detail enhancement.

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