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A Novel Retinex Algorithm and its Application to Fog-degraded Image Enhancement

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Abstract: Fog-degraded images enhancement is an important problem in the field of image enhancement and computer vision. To overcome the halo artifact, enhance the contrast and better preserve the color of original image, a novel Multi-Scale Retinex color image enhancement method is proposed in this paper. An adaptive anisotropic Gaussian filtering method and its principle are described. The orientation of the Gaussian filter long axes is determined according to the gradient orientation in the position. The procedure of algorithm is given in this paper and applied in the fog-degraded images enhancement. Finally, by comparison with histogram equalization and Multi-Scale Retinex method, the experimental results show that the proposed method can offer better performance in fog-degraded image enhancement. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Image enhancement, Fog-degraded image, Multi-Scale Retinex, Adaptive filter.

1. Introduction

The main purpose of image enhancement is to process an image in order to achieve a good result which is more suitable than the original image for a specific application. Providing digital images with wide dynamic range and higher content of visual detail is a strong requirement in these applications such as computer vision, pattern recognition, segmentation, and image analysis. The common ways used for enhancing images are usually by means of the contrast stretching, histogram processing or the Laplacian operator [1].

The degradation of images by fog and mist is a familiar problem in our life. In foggy weather, the contrast of images is drastically degraded and the color is partial gray and white mainly due to the presence of considerable number of atmospheric particles such as dust, mist and fumes, which makes some applications such video surveillance, target tracking very sensitive to weather conditions. We therefore need to develop techniques to fit the original scene with a wide dynamic range in devices with a much lower dynamic range. Many scientists have researched the clearness technique in bad weather conditions from two aspects including image enhancement and image restoration to improve the system robustness.

Some achievements have been made in the past years. When some priori information about the scene model is known beforehand, J. P. Oakly and B. L. Satherly proposed their algorithm to enhance the image contrast in haze condition. An inverse problem to recover the physical model is first proposed, and then using the model to enhance the image contrast on a pixel-by-pixel basis [2]. However, the algorithm depends on knowledge of some parameters. When the assumption of known the scene structure can not be satisfied, the algorithm will be restricted for practicality. Srinivasa G. Narasimhan and Shree K. Nayar presented the physics-based method to compute scene structure and restore contrast of the scene from two or more images of same scene taken in different bad weather conditions. The algorithm is effective under some weather condition. However, the precondition may be difficult to be satisfied in practice [3].

Recently, single image fog removal has made significant progresses. A user interactive de-weathering method using a single image is proposed by Srinivasa G. Narasimhan and Shree K. Nayar. The method requires some coarse depth information [4]. Raanan Fattal presented a single image defog method for estimating the transmission in hazy scenes [5]. The method solves a non-linear inverse process and therefore its performance greatly depends on the assumption that the transmission and surface shading are locally uncorrelated. Raanan Fattal's method cannot handle heavy haze images well. Kaiming He proposed a dark channel prior method for single image haze removal [6]. The dark channel prior means that at least one color channel has low intensity or almost zero pixel values within a haze-free image except sky area. He's approach based on the statistics of haze-free outdoor images and obtain impressive results. Nevertheless, the processing time by using soft matting is complex and cannot be used in real-time system. A fast haze removal algorithm based on a fast bilateral filtering combined with dark colors prior is presented which has a fast execution speed and improved Kaiming' algorithm [7]. The success of these methods lies in using some prior information or assumption. Although the fog removal methods have made significant progresses, the problem of haze removal is a challenging because of the unknown transmission and ill-posed conditions.

In this paper, we propose a novel Multi-Scale Retinex color image enhancement method combined the advantage of adaptive filtering and color constancy. Some experimental results show that the proposed method can offer good performance in fog-degraded image enhancement.

The organization of the rest of paper is organized as follows. Section 2 briefly reviews the Retinex algorithm and its application in image processing. In Section 3, the improved Multi-Scale Retinex algorithm is presented. In Section 4, we compare and analysis the experimental results. Conclusions are given in Section 5.

2. Retinex Approaches for Image Enhancement

The Retinex algorithm of Land and D. J. Jobson was color constancy algorithm and one of the most famous theories to model and explain how the Human visual system (HSV) perceives colors. The basic Retinex model is based on the assumption that the HVS operates with three retinal-cortical systems, each processing independently the low, middle, and high frequencies of the visible electromagnetic spectrum [8]. The color constancy refers to the resilience of perceived color and lightness to spatial and spectral illumination variation. Some researches have shown that Retinex algorithm can improve consistency of output as illumination changes by color constancy processing [9]. Retinex algorithm has been successfully applied to image enhancement and restoration for degraded foggy images. The Retinex theory is used to deal with the compensation of unfavorable illumination effects from images. The basic motivation of homomorphic filtering type Retinex algorithms is that the reflectance image corresponds to the sharp details in the image (i.e. edges), whereas the illumination image is expected to be spatially smooth. The illumination component is estimated as a smooth version of input image, where the spatially smooth is usually obtained as a wide Gaussian kernel convolution with the input image. A haze removal method based Retinex and dark channel prior is effective and computationally simple [10]. The basic Retinex model is based on the assumption that the HVS operates with three retinal-cortical systems, each processing independently the low, middle, and high-frequencies of the visible electromagnetic spectrum [11]. The equation that describes the calculation of a Single Scale Retinex (SSR) is:

$$R_i(x,y) = \log(I_i(x,y)) - \log(I_i(x,y) * F(x,y)), \quad (1)$$

where the subscripts $i \in R,G,B$ represent the three color bands, respectively. $I_i(x,y)$ is the image intensity in the *i*-th spectral band. $*$ is the convolution operator. $R_i(x,y)$ is the *i*-th output component of Retinex algorithm and the $F(x,y)$ is a Gaussian surrounding function, defined as:

$$F(x,y) = Ke^{-(x^2+y^2)/\sigma^2}, \quad (2)$$

where σ is the Gaussian surround space constant, and K is selected such that

$$\iint F(x,y)dxdy = 1, \quad (3)$$

The SSR algorithm shows exceptional promise for dynamic range compression, but does not provide good tonal rendition simultaneously. A Multi-Scale Retinex (MSR) algorithm combines several SSR outputs to produce a single output image. The advantage that the MSR has over the SSR is in the combination of scales which provide both good dynamic range compression and color constancy, and good tonal rendition at the same time. The MSR output is simply a weighted sum of outputs of several different SSR outputs which can be compactly written as:

$$R_i(x,y)=\sum_{n=1}^{N}W_n\{\log(I_i(x,y))-\log(I_i(x,y)*F_n(x,y))\}, \quad (4)$$

where N is the number of scales being used (usually choose three). W_n are the weighting factors for the n-th scales. Usually, these weights are taken to be equal. $W_n=1/3$, n=1,2,3 was sufficient for most applications. Where $F_n(x,y)$ is defined as: $F_n(x,y)=Ke^{-(x^2+y^2)/\sigma_n^2}$.

A series of tests with one small scale ($\sigma_n<20$) and one large scale ($\sigma_n>200$), the need for a third intermediate scale was immediately apparent which can produce a graceful rendition without visible "halo" artifacts near strong edges.

3. The Proposed Algorithm

The primary goal of Retinex theory is to decompose a given image into two different images, the reflectance image, and the illumination image. The benefits of such decomposition include the possibility of removing illumination effects of back/front lighting. Recovering the illumination from a given image is known to be a mathematically ill-posed problem. Although the MSR algorithm has achieved a good result in image enhancement, and the "halo" artifacts are suppressed, there are still slight "halo" artifacts at the edges [12]. The result is illustrated in Fig. 2. Note that the dynamic range compression of the processed image is strong and some details are visible, but the detail in the some dark region can not discriminate.

The traditional Retinex algorithm firstly applies surrounding function to estimate image background illumination, and then it removes the background illumination from the original images in logarithmic space to obtain image enhancement. From discussed in Sect.2, we know that the function $F_n(x,y)$ has play a very important role in MSR algorithms. The estimation of illumination is the core procedure because various smoothing methods may be different effects in image enhancement. The surrounding function is usually the isotropic Gaussian filter. But there is an apparent deficiency. The background illumination is obtained by isotropic low-pass filter, so blur always appears on the boundary of the objects with strong contrast, which produces the halo phenomenon. We can avoid use this isotropic filter but an anisotropic adaptive filter in order to provide a dynamic range compression, good tonal rendition, but not halo artifacts simultaneously.

In this section, an enhancement algorithm based modified MSR is presented. According to the above analysis, we know that the projection of isotropic Gaussian low-pass filter is a circle in the x-y plane [13, 14]. The mathematical expression can be expressed by (Shown as Fig. 1(a)):

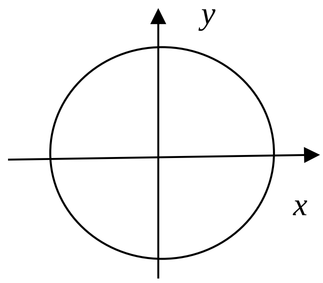
$$F(x,y,\sigma)=\frac{1}{2\pi\sigma}\exp\left\{-\frac{1}{2}\left(\frac{x^2+y^2}{\sigma^2}\right)\right\}, \quad (5)$$

The filter consists in a signal controlled variation of shape and orientation. If we select a different scale in x- and y-axis direction, a simple case of an oriented anisotropic Gaussian filter in two dimensions is given as (Shown as Fig. 1(b)):

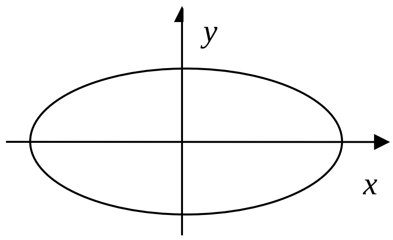
$$F_\theta(x,y,\sigma_x,\sigma_y)=\frac{1}{2\pi\sigma_x\sigma_y}\exp\left\{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}\right)\right\}, \quad (6)$$

The Fig. 1(c) is the rotation of the Fig. 1(b). The convolution relationship between Fig. 1(c) and Fig. 1(b) is given by:

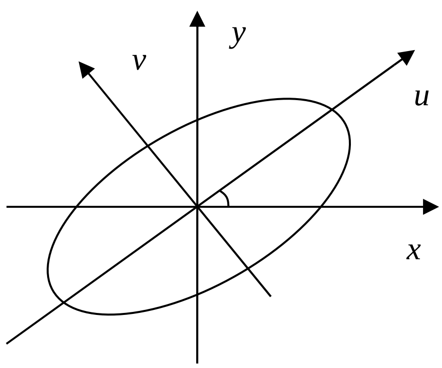
$$\begin{pmatrix}u\\v\end{pmatrix}=\begin{pmatrix}\cos\theta & \sin\theta\\-\sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}x\\y\end{pmatrix}, \quad (7)$$



(a) Gaussian filter



(b) Anisotropic Gaussian filter



(c) Rotation of Fig.1. (b)

Fig. 1. The projection of different Gaussian filters.

The *u*-axis being in the direction of θ, and *v*-axis being orthogonal to θ. Replacing Eq. (7) in Eq. (6), the filter operator is synthesized by

$$F_\theta(x,y,\sigma_x,\sigma_y,\theta)=\frac{1}{2\pi\sigma_x\sigma_y}\exp\left\{-\frac{1}{2}\left(\frac{(x\cos\theta+y\sin\theta)^2}{\sigma_x^2}+\frac{(-x\sin\theta+y\cos\theta)^2}{\sigma_y^2}\right)\right\} \quad (8)$$

So we have achieved an arbitrary orientation Gaussian filter.

From the above equation, we know that the parameters of θ, σ_x and σ_y play an important role in adaptive filtering algorithm, especially the rotation angle. The original image contains abundant information such as contrast and edge, etc. In order to enhance the image details but produce little halo, we design the parameters of filter based on statistical characteristics of original image. The orientation of adaptive filter's long-axis is designed according to the gray gradient orientation in the image position.

The normal orientation of point is substituted for the gradient. The horizontal and vertical direction gradient can be obtained by the convolution of horizontal and vertical directional derivative of Gaussian function and image. The relationship may be written in the more generalized form as shown in Eq. (9):

$$\begin{cases} E_x=\dfrac{\partial F(x,y)}{\partial x}*I_0(x,y) \\ E_y=\dfrac{\partial F(x,y)}{\partial y}*I_0(x,y) \end{cases}, \quad (9)$$

where the $I_0(x,y)$ is the intensity of original image in point (*x*, *y*).

The gradient amplitude and phase of point (*x*, *y*) can be computed by Eq. (10):

$$A(x,y)=\sqrt{E_x^2(x,y)+E_y^2(x,y)}$$
$$\theta_g(x,y)=arctg\left(\frac{E_x(x,y)}{E_y(x,y)}\right), \quad (10)$$

The relationship between θ in Eq. (8) and θ_g is:

$$\theta=\theta_g+90^0, \quad (11)$$

Replacing Eq. (11) in Eq. (8):

$$F_\theta(x,y,\sigma_x,\sigma_y,\theta_g)=\frac{1}{2\pi\sigma_x\sigma_y}\exp\left\{-\frac{1}{2}\left(\frac{(-x\cos\theta_g+y\sin\theta_g)^2}{\sigma_u^2}+\frac{(-x\sin\theta_g-y\cos\theta_g)^2}{\sigma_v^2}\right)\right\} \quad (12)$$

The adaptive anisotropic filter makes it possible to obtain good estimates of local structure and orientation. In the proposed novel MSR method, we adopted the Gaussian surrounding function $F'(x,y)$ as Eq. (13). In the smooth regions of a fog-degraded image, the traditional MSR method is used to enhance the image contrast, Otherwise, in the sharp edge, the anisotropic filter' MSR method is adopted.

$$F'(x,y)=\begin{cases} F(x,y), & if \quad A(x,y)\le T \\ F_\theta(x,y), & if \quad A(x,y)>T \end{cases}, \quad (13)$$

4. Experimental Results and Analysis

To test the performance of our enhancement method for enhancing fog-degraded images, some experiments have been conducted on outdoor real scene images taken in foggy condition. Original image of size 1024×1024 shown as Fig. 2(a), some details in distant scene are illegible. The RGB components of Fig. 2(a) have been enhanced by histogram equalization separately and recombined to form the output image, shown in Fig. 2(b). The enhanced image by the MSR method of Ref. [11] is shown in Fig. 2(c). In order to simplify calculating, we adopt $\sigma=2.5$, $\sigma_x=2$ and $\sigma_y=0.3$ in the proposed method. The enhanced image is shown in Fig. 2(d). From the Fig. 2(b) and Fig. (d), we can see that our proposed method can improve the contrast. The building bottom in distance is more clearly in Fig. 2(d) than the images in Fig. 2(b) and Fig. 2(c). The contrast and clarity of the images are enhanced significantly.

To quantitatively assess different image enhancement algorithms, we adopt the mean, standard deviation and entropy to evaluate the performance. Here we normalized the *HSV* components of image into [0,1]. Table 1 shows the overall result of different methods enhancement. The subjective and the objective evaluations show that the proposed algorithm is very effective in details preservation in foggy image enhancement.

The result of the experiment for addition is illustrated in Fig. 3 and Fig. 4. The foggy input image shown in Fig. 3(a), Fig. 4(a) and the enhanced image shown in Fig. 3(b), Fig. 4(b) have tested the proposed algorithm performance.

(a) Fog-degraded original image.

(b) Method of histogram equalization.

(c) Method of Ref. [11].

(d) Proposed method.

Fig. 2. Example of enhancement of a fog-degraded image.

Table 1. Comparisons of H, S and V component in different images by mean, standard deviation and entropy.

Different image	Mean, standard deviation and entropy		
	***H* component**	***S* component**	***V* component**
Fig. 2(a)	0.3193/0.1178/2.6435	0.0180/0.0003/2.5607	0.6037/0.0054/6.1737
Fig.2(b)	0.4469/0.0665/6.9219	0.1227/0.0216/6.3135	0.5198/0.0809/7.9825
Fig.2(c)	0.2957/0.0705/6.8763	0.1127/0.0152/6.3529	0.5266/0.0308/7.6165
Fig. 2(d)	0.2162/0.0463/6.9302	0.1523/0.0146/6.5577	0.5368/0.0191/7.1244

(a) Original image

(b) Result of enhanced by the proposed method

Fig. 3. Example of enhancement.

(a) Original image

(b) Result of enhanced by the proposed method

Fig. 4. Example of enhancement.

5. Conclusions

The MSR algorithm has achieved a good result in fog degraded image enhancement. However, there are still slight "halo" artifacts at the edges region. In order to better preserving the details of an image, combining the advantage of adaptive filtering and color constancy, a modified MSR algorithm is proposed. The paper describes the principle of adaptive filtering and algorithm implementation scheme. Experiments and objective evaluations have shown that the proposed algorithm provides a more efficient to preserve detail and color fidelity in foggy image enhancement.

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