International Journal of Hybrid Information Technology
Vol.7, No.4 (2014), pp.353-364
http://dx.doi.org/10.14257/ijhit.2014.7.4.30

Retinex Algorithm on Changing Scales for Haze Removal with Depth Map

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Abstract

In order to improve the traffic visibility in haze weathers, a Retinex algorithm based on the changing scale for haze removal with a depth map is proposed. It requires the haze image dark channel prior treatment to obtain the estimated depth map. Then it is according to the depth map to calculate Retinex scales for different parts of a hazy image. Finally a single scale Retinex transform is performed for each part of the image. Experimental results show that the algorithm can effectively improve the traffic visibility of hazy images without halo phenomena. Compared with the existing multi-scale Retinex algorithm MSR, it has the higher speed and better enhancement effect for the images that have greatly different scene depths.

Keywords: *Dehaze, dark channel prior, transmission map, Retinex, changing scale*

1. Introduction

At present, there are two main kinds of methods to enhance haze images: one is based on image processing, and the other is to restore a haze image based on an atmospheric scattering model [1]. The common method based on image processing is the histogram equalization which is a classical algorithm that has the advantage for the simple implementation. But it does not take into account the characteristics of different regions in a haze image; therefore it is difficult to get satisfactory results in many dehaze occasions. According to the features of the human vision, Edwin proposed Retinex theory in 1977 [2]. After a few years, Jobson creatively used a center-surround algorithm to estimate luminance components, which reduces a large amount of computation of Retinex [3]. In order to make the Retinex algorithm highlight the details and obtain the better color restoration ability at the same time, Jobson *et al.*, suggested a multi-scale Retinex (MSR) algorithm and a multi-scale Retinex with color restoration (MSRCR) algorithm [4]. Although MSRCR can overcome the main shortages of the Single Scale Retinex (SSR), there are still the following two problems: firstly, the algorithm usually sums three scaled and weighted parts which are treated for RGB three components respectively, causing its high complexity; secondly, a multi-scale filter leads to halo phenomenon seriously in the edges where the color changes greatly [5].

The research for Retinex based algorithms becomes a hot topic in recent years. To take off the halo phenomenon as much as possible, Xu *et al.*, estimated the illumination values by using a mean shift smoothing filter then overcame the uneven illumination and eliminated the halo phenomenon [6]. In the view of the complexity of the Retinex based algorithm, Jean *et al.*, studied on the relationship between Retinex theory and the discrete Poisson equation, and put forward a rapid application [7].

ISSN: 1738-9968 IJHIT

(a)

(b)

(c)

Figure 1. Hazy Images and the Result of SSR: (a) Raw Hazy Images; (b) Results of SSR (c=10); (c) Results of SSR (c=110)

On the basis of the previous algorithms, we propose a changing scale Retinex algorithm based on the features of the depth to resolve the existing problems of the Retinex. The new algorithm combines the Retinex algorithm with the transmission map, and uses different scales of the Gauss filter in different regions according to depths. As the experimental results shown, the new algorithm has the enhancement effect with a fast processing speed, and it can also greatly eliminate the halo effects in haze images that have great differences in scene depths.

2. Relationship between Depth and Retinex Scale

The MSR algorithm is widely used for the enhancement of haze images as well as uneven illumination images. But it has also some disadvantages such as the high complexity for computing and the halo effects.

The MSR is weighted by three results of SSR, which calculates the enhancement results with the large, middle and small scales respectively. Observing in Figure 1, we can find some features of the SSR algorithm: when the value of the scale parameter c is large, the Gauss function is flat, and the incident component estimation is smoother after convolution, so color fidelity ability is good, but the dynamic compression ability is poor and the details of the image enhancement effect are not obvious. On the contrary, when c is small, the Gauss function is relatively steep, the dynamic compression ability of the SSR is strong, the result has highlighted image details, but the color fidelity ability is weak [8].

As shown in Figure 1, we can also see that the effect of the depth map to the Retinex result: Figure 1(b) is the result of the small scale SSR, its far distant details are clear (see the red box of (b)), its near objects have color distortion phenomenon (see the green box of (b)); Figure 1(c) is the result of the large scale SSR, its far distant details are vague (see the red box of (c)), its near objects have good result without any color distortion (see the green box of (c)).

As known, the far distant objects are fuzzy and color bleak in the haze images, so a small scale Gauss filter has the better effect in this region; on the contrary, the near objects are clear and bright, so a large scale Gauss filter is needed to keep their color fidelity [15].

Hence, we propose a changing scale Retinex algorithm for haze images with different depths: using a large scale Gauss filter in the regions near the camera, and using a small scale Gauss filter in the regions far from the camera. So the following benefits can be obtained: firstly, the far distant details are enhanced; secondly, the colors of nearby area are maintained; thirdly, the halo is not produced because the region where the color changing a lot is always near the camera and the lager scale SSR is used in this area; at last, the complexity of the single scale transform algorithm is less than that of the multi-scale transform. The next work is to obtain the depth map that can be sought by using the dark channel prior theory.

3. Dark Channel Prior and Retinex Algorithm

This section briefly introduces the implement method of the dark channel prior and the theory of the Retinex algorithm, and presents the values of the three scale parameters of the MSR, to make a right way for fog image enhancement.

3.1. Dark Channel Prior

In Computer vision, the fog imaging model described by the following equation is widely used [9].

$$I(x) = J(x)t(x) + A(1 - t(x)) \tag{1}$$

In the formula, I represents a raw haze image, J is for the scene radiance, A stands for the global atmospheric light, and t is the medium transmission describing the portion of the light that is not scattered and is close to the camera. The goal of the dehaze is to recover J, A and t from I. Among them, the transmission graph t can be expressed as [10]:

$$t(x) = e^{-\beta d(x)} \tag{2}$$

$J(x)t(x)$ on the right of the equation (1) is called the direct attenuation, and $A(1-t(x))$ is called airlight [11]. The direct attenuation term describes the part of the scene radiance decaying in a transmission medium, and the airlight component which is caused by previously scattered light leads to the offset of the scene colors. In formula (2), β is the scattering coefficient of atmospheric and it shows that the scenery light exponentially decay with depth d.

In 2009, He *et al.*, proposed the dark channel prior theory according to the statistical law of the large amount of outdoor images: in the vast majority of a non-sky region, a number of pixels have very low values on one color channel at least, namely the dark channel. An image of the dark colors is defined as

$$J^{dark}(x) = \min_{y \in \Omega(x)} \left(\min_{c \in \{r,g,b\}} J^c(y) \right) \tag{3}$$

Where, J^c is a color channel of J and $\Omega(x)$ is a local patch centered at x. Through a large number of statistical experiments, for the image of good quality, it has

$$\min_{\Omega}(\min_{c}(J^c)) \to 0 \tag{4}$$

The assumption is that the transmission map $t(x)$ is a constant in a local block, according to the haze imaging model, we make both sides of formula (1) dark color transform

$$\min_c \left(\min_{y \in \Omega(x)} \left(\frac{I^c(y)}{A^c} \right) \right) = t(x) \min_c \left(\min_{y \in \Omega(x)} \left(\frac{J^c(y)}{A^c} \right) \right) + (1 - t(x)) \tag{5}$$

In light of the dark channel prior theory, the first item of formula (5) is approximately equal to 0, so formula (5) is equivalent to

$$t(x) = 1 - \min_c \left(\min_{y \in \Omega(x)} \left(\frac{I^c(y)}{A^c} \right) \right) \tag{6}$$

In a haze image, the fog is thick, so the values of transmission maps are small. That is to say, the transmission map t can accurately reflect the field depth of the image. Thus, we can also estimate the corresponding atmospheric light value A.

3.2. Retinex Algorithm Implementation

The Retinex theory is a kind of model about how the human visual system perceives object brightness and colors [2]. The word “Retinex” is the combination of "Retina" and "Cortex". Compared with the traditional image enhancement algorithms, the Retinex can achieve a balance in the dynamic gray range compression, edge enhancement and color constancy [13].

The basic idea of the Retinex is that an original image is composed of light image $L(x, y)$ and object reflection properties $R(x, y)$, which can be expressed as

$$S(x, y) = L(x, y) \cdot R(x, y) \tag{7}$$

Where, L determines the dynamic range of the image, R determines the intrinsic nature of the image. The essence of the Retinex enhancement is to eliminate the influence of the luminance component L from the original image. In order to obtain the reflection component R which can reflects the essential features of the image, the mathematical form of the SSR algorithm is presented as follows

$$R_i(x, y) = \log I_i(x, y) - \log[F(x, y) * I_i(x, y)] \tag{8}$$

Where, $R_i(x, y)$ is the output of the SSR in the *ith* color channel, $*$ denotes the convolution operation, $F(x, y)$ is the surround function, *log* is the natural logarithm. The convolution part in formula (8) is usually the considered estimation to the luminance image L. We use the Gauss function as the surround function

$$F(x, y) = K \exp[-(x^2 + y^2)/c^2] \tag{9}$$

Where, c is the scale parameter for the Gauss function, which determines the scope of convolution. The smaller c is, the greater dynamic range is compressed and the clearer image detail is; on the contrary, if c is large, the color is natural and the overall visual effect is well, but the details are not good enough. K is a normalization factor that is selected such that

$$\iint F(x, y)dxdy = 1 \tag{10}$$

In practical applications, the MSR is more widely used to achieve good results in the preservation and color consistency. The output of the MSR is the sum of several SSR results at different scales

$$R_{MSR_i} = \sum_{n=1}^{N} w_n R_{n_i} \tag{11}$$

(a) (b)

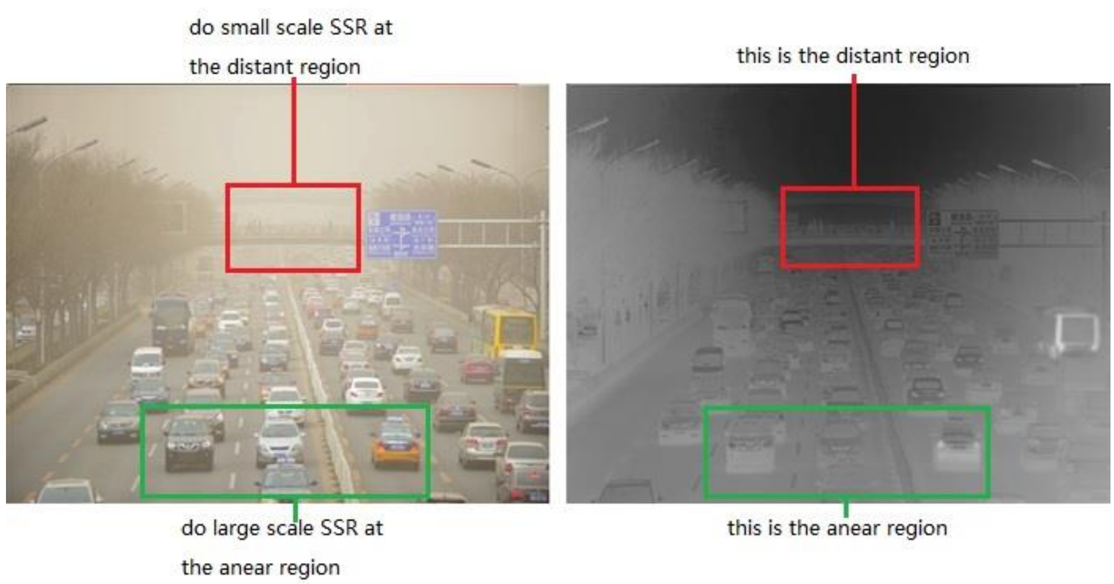
Figure 2. Hazy Image and the Result of MSR: (a) Hazy Image; (b) Result of MSR

In the formula, N is the number of scales, R_{n_i} is the SSR result of the *nth* scale in the *ith* color channel (its Gauss filter scale is c_n), R_{MSR_i} is the result of the MSR in the *ith* color channel, w_n is the weighting coefficient of the *nth* scale. It always is weighted on average in formula (11).

An important factor in determining the MSR effect is of the scale amount and value. In reference [4], the amount of scales is 3 and 250, 80, 20 are chosen as their scale values. This paper is concerned with the haze image in which the characteristic is scenery blurred, so we choose parameters that can highlight the details. The scales of the MSR in this paper are 110, 50, 10 respectively. It is the MSR result of a haze image in Figure 2(b). As it can be seen, there is the halo between leaves and pavement.

4. A Changing Scale Retinex Algorithm Based on Depth Map

In our algorithm, the Retinex scale is not constant. It takes different values in different regions, and the scale values are determined by the image depth. First of all, we get a dark channel image using a 15×15 mask, and calculate the transmission map $t(x,y)$ according to formula (6). The value of $t(x,y)$ is between 0 to 1, and which represents how far away it is from the camera.



(a) (b)

Figure 3. Hazy Image and the Estimated Transmission Map: (a) Hazy Image; (b) Estimated Transmission Map

Figure 3(b) is a dark channel transmission map processed by a 15×15 mask, and it reflects the depth of the haze image. In the transmission map, the dark region is far away from the camera and the bright region is opposite. In our method, it is doing a small scale transformation in the place far from the camera and doing a large scale transformation in the place near the camera. We assume that it has a linear relationship between the scale parameter $c(x,y)$ and the transmission map $t(x,y)$.

$$c(x,y)=\frac{t(x,y)-\min(t(x,y))}{\max(t(x,y))-\min(t(x,y))}? 100 \quad 10 \tag{12}$$

Where, $\max(t(x,y))$ and $\min(t(x,y))$ are the maximum and minimum values of $t(x,y)$ respectively. Thus, we obtain the scale $c(x,y)$, and its range is 10 to 110, from a small scale to a large scale. According to the scale parameters obtained by formula (12), we perform the Gauss filter for the haze image, and then calculate Retinex results. The algorithm flow chart is illustrated in Figure 4.

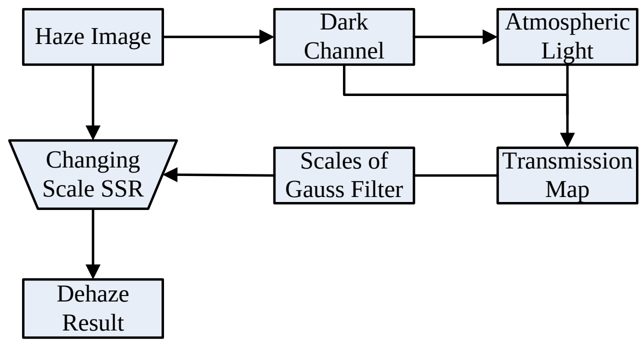


Figure 4. Flow Chart of Haze Removal Method

5. Linear Stretching and Image Quality Determination

A part of pixel values are not in a scale of 0-255 after performing Retinex or our method [14], as shown in Figure 5. So the processed result needs linear stretching. In general, we get the low saturation point as

$$d_{low}=\mu-r\sigma \tag{13}$$

and the high saturation point is as

$$d_{high}=\mu+r\sigma \tag{14}$$

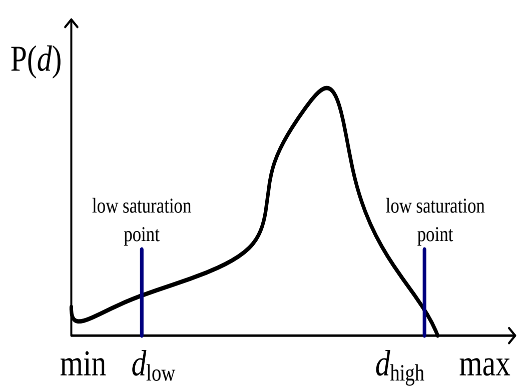


Figure 5. Histogram of Enhanced Image

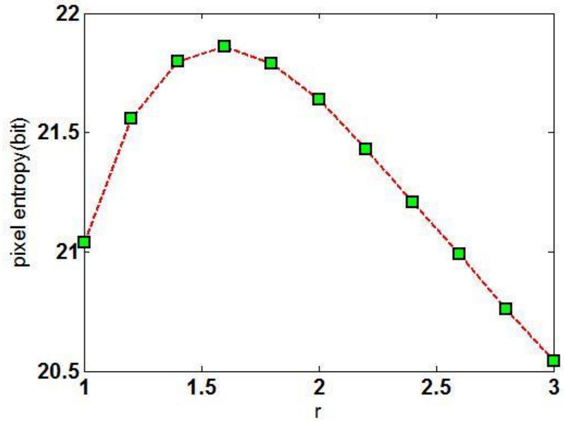


Figure 6. Pixel Entropy of Processed Image Changes with r, its Original Image is in Figure 1(a)

The pixels between the low saturation point and the high saturation point are stretched into 0-255. The μ and σ are respectively the mean and standard deviation of the pixel values [17]. Where, *r* is the undetermined coefficient, using a small *r* can enhance the contrast and using a large *r* can keep the pixel information in the histogram. So the value of *r* is very important to the enhanced effect, see Figure 7.

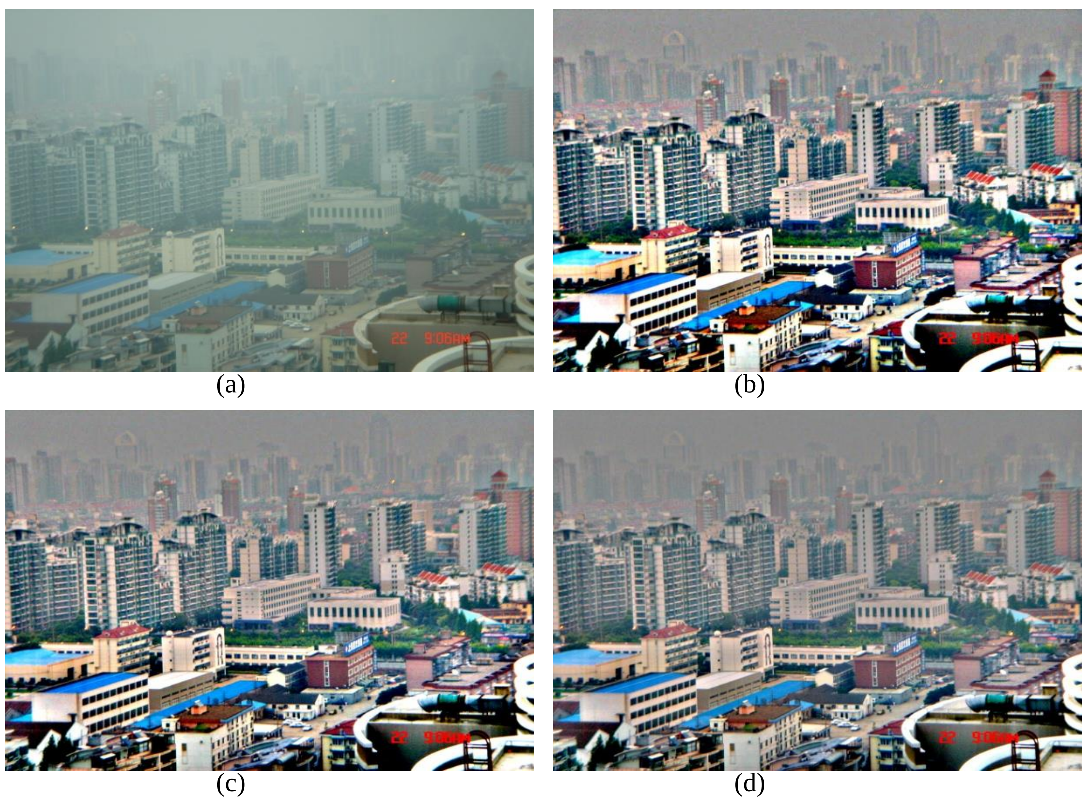


Figure 7. Image Stretching with Different r and Pixel Entropy Values: (a) Original Image, Pixel Entropy = 19.92; (b) *r*=1, Pixel Entropy = 21.04; (c) *r*=1.4, Pixel Entropy = 21.80; (d) *r*=2, Pixel Entropy = 21.64

On the basis of a large number of experiments, this paper suggests to use pixel entropy for determining the quality of the enhanced image and choosing the *r* value [18, 19, 20]. The larger pixel entropy is, the better the image quality is. This rule is suit to both the Retinex and our new algorithm.

6. Experimental Results

As examples, the two typical images are used for the comparison of the new algorithm and the MSR algorithm. For these two images, the new algorithm has the following advantages: it has the better color fidelity ability in the vicinity, highlights the far distant scene details, and does not produce the halo even the boundary color changes greatly.

The MSR generally requires 3 times of the SSR in calculation with 3 scales and sums them by weighted values. The SSR algorithm is not complex, but the MSR is about 3 times of the SSR. The new algorithm only does the SSR once, so it consumes less than the MSR.

(a)

(b)

Figure 8. Results of MSR and our New Algorithm: (a) Result of MSR; (b) Result of the Proposed Algorithm

The small scale SSR will produce the halo in the region where the color changes a lot, where the halo is in the MSR comes from. In the haze image, the color greatly changes only in where is near to the camera, so the large scale SSR will not produce the halo in this area.

The main disadvantages of the new algorithm are: (1) the applicable scope is not extensive, and its effect is obvious to haze images that have a large difference in depth; to the others, the effect is not so good; (2) Its result in the sky area is bad, because the transmission map in the sky area is small, and the small scale SSR outstands unnecessary details.

Table 1. Comparison of MSR and our new Algorithm

	MSR	Our new algorithm
Halo	Yes	No
Time	T	T/3
Depth map	Did not take into account	Take into account

7. Conclusions

To overcome the halo problem in the MSR based algorithms, a new algorithm based on Retinex is proposed for the enhancement of haze images. The dynamic scales are used in the algorithm, which is different to the SSR and the MSR, and the scales are determined automatically based on the depth map of the processed image. The depth map is calculated by using the dark channel prior. In light of the depth map, the Retinex scales are calculated from place to place in the hazy image. For the new algorithm, the testing and comparison results demonstrated: (1) it determines the Retinex scales based on the variation of the images, does not need to fix the scales as constants, as the SSR or MSR algorithms do; (2) it can overcome the halo problem in most cases; (3) it reduces the computing complexity by comparing to the MSR which has relative stable enhancement result than the SSR, so, it has the faster speed. The continuation of the research work is to test more haze images, and then do some modifications.

Acknowledgement

This research is financially supported by the National Natural Science Fund in China (grant no. 61170147).

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