Acta Technica 62, No. 3B/2017, 573–580

A contrast limited adaptive histogram equalization dark channel prior haze removal algorithm[1]

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Abstract. In order to solve the problem of slow processing speed and easy distortion of the sky area, a new method based on adaptive image segmentation is proposed. Firstly, the adaptive threshold segmentation is used to segment the haze image. Then, the segmented image is processed separately, which can solve the problem of distortion in the sky. In the implementation of the algorithm, the bilateral filter is used to fine the transmittance, which can significantly reduce the amount of calculation. Adaptive histogram equalization method is used to enhance the image of the restored image. The computer simulation results show that the algorithm can effectively improve the visual effect and improve the image quality. The algorithm has low computational complexity and easy implementation. The algorithm can be applied to most fog images, but the color saturation may occur when the image contrast is high.

Key words. Dark channel prior, adaptive threshold segmentation, transmittance, fast bilateral filter, contrast limited adaptive histogram equalization (CLAHE).

1. Introduction

The scattering, reflection and absorption of suspended particles in the airlead to outdoor image detail loss. The performance of outdoor surveillance and intelligent navigation system are serious impacted. Therefore, the haze removal of image is urgent and has become a new research hotspot. At present, the methods to remove haze are mainly divided into two categories: the enhancement method based on

[1]This paper belongs to the project of the "Tianjin research program of application foundation and advanced technology" No. 16JCYBJC28800; "National undergraduate innovative training program" No. 201410069033; Tianjin university of commerce young and middle-aged international training program.

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image processing [1–3] and the restoration method based on physical model [4–7]. The algorithm proposed in this paper belongs to image recovering method. The dark grey statistics lawn is combined with atmospheric scattering model by K. He [8]. As a result, the dark channel prior single image haze removal algorithm is proposed by them. The haze is removed better by the algorithm. However, there are still many shortcomings, such as the higher time complexity, the poor sky region processing effect. When the brightness between the sky area and other areas are close, the other area in the image is blur. To solve these problems above, a new haze removal algorithm is proposed in this paper. Firstly, the image foggy image is divided by adaptive threshold segmentation. Secondly, the speed is increased by bilateral filtering optimizing transmittance. Lastly, the recovered image contrast is enhanced by limit contrast adaptive histogram equalization. The performance of image haze removal is obtained by improving image contrast.

2. A prior haze removal algorithm based on dark channel

A dark channel statistical law is proposed by K. He after analyzing a lot of non-haze images. The law points out that there is a very low value area in R, G, B channel in the majority of non-haze images.

The dark channel $J^{\rm dark}$ for a given image $J(x)$ is defined as

$$J^{\rm dark}(x) = \min_{y\in\Omega(x)}\left(\min_{c\in\{r,g,b\}} J^{\rm c}(y)\right), \tag{1}$$

where $J^{\rm c}$ represents the color channel of $J(x)$, $\Omega(x)$ represents the dark color of the regional in the center of x, the intensity of the dark color region is close to 0.

According to the definition of the dark channel $J^{\rm c}$, the image transmission can be calculated by the formula:

$$t\left(x\right) = 1 - \omega \min_{c}\left(\min_{y\in\Omega(x)} \frac{I^{\rm c}\left(y\right)}{A^{\rm c}}\right), \tag{2}$$

where ω $(0 < \omega \leq 1)$ is the adjustment factor. However, completely removing haze will make images look unnatural and lose depth sense. The constant ω is introduced to preserve the haze in the distance.

Finally, according to image haze model (3), the image can be restored.

$$J\left(x\right) = \frac{I\left(x\right) - A}{\max\left(t\left(x\right), t_{\rm a}\right)} + A\,, \tag{3}$$

where A is the atmospheric light. In the haze image, various pixel is descended according to brightness. The maximum value in the top 0.1 % points in the position is used as A. t_0 is the low limit of $t(x)$. Value 0.1 is the typical for t_0.

3. Improved haze prior removal algorithm based on dark channel

In algorithm proposed by K. He, the process is slow and sky area is easy to be distorted. To solve the problems above, a dark channel prior haze removal algorithm based on adaptive threshold segmentation is proposed. The image is dived firstly and processed separately by adaptive threshold segmentation. As a result, the sky area distorted can be solved. The amount of calculation algorithm is reduced significantly by using bilateral filtering optimizing transmittance. The recovered image is enhanced by limit contrast adaptive histogram equalization.

3.1. OTSU adaptive threshold segmentation

OTSU adaptive threshold segmentation algorithm was proposed by Otsu in 1979. The algorithm is simple and can avoid the influence of image brightness and contrast. In OTSU algorithm, the image is divided into background and foreground by gray characteristic. The greater the variance between foreground and background is, the larger difference between the two parts is. If the foreground and background divided wrongly, the differences between the two parts will become smaller. Therefore, maximizing the classification variance segmentation will lead to the smallest error probability. Image gray histogram is divided into two parts by the best threshold in OTSU algorithm. The maximum is got in the classification variance between the background and foreground. namely, separation is the largest.

The adaptive threshold of the algorithm is determined as follows:

$$R = \sqrt{R_{\mathrm{r}}^2 + R_{\mathrm{g}}^2 + R_{\mathrm{b}}^2}\,, \tag{4}$$

where R_{r}, R_{g} and R_{b} express the threshold values of red, green and blue component in the current pixel respectively. They are defined as

$$R_k = (W_{\max} - W_{\min})\left(\mathrm{p}_1\left(\mathrm{k}\right)/R_{\max}\right)^n + W_{\min} k \in (r, g, b)\ . \tag{5}$$

Here, p_1 represents the current pixel, p_1 (r), p_1 (g), and p_1 (b) represent the red, green, blue components in P1 pixel respectively. Symbols $R_{\max}$, $G_{\max}$, $B_{\max}$ refer to the largest red, green and blue components in the whole image respectively. Values $n = 1, 2, 3$ represent the linear, the second order matrix and the third order matrix respectively. Symbols $[W_{\min},\ W_{\max}]$ represent the minimum and maximum map weight range.

If the two pixels p_1 and p_2 satisfy the following conditions

$$|\mathrm{p}_1 - \mathrm{p}_2| = \sqrt{(\mathrm{r}_1 - \mathrm{r}_2)^2 + (\mathrm{g}_1 - \mathrm{g}_2)^2 + (\mathrm{b}_1 - \mathrm{b}_2)^2} < R\,, \tag{6}$$

where $|\mathrm{p}_1 - \mathrm{p}_2|$ represents the spatial distance between the two pixels p_1 and p_2.

3.2. Bilateral filtering fine transmittance

Transmittance image is refined and smoothed by the image haze removal algorithm mentioned in [11]. However, this method needs to solve the giant Laplace matrix equation, which improves algorithm complexity and makes algorithm speed slow. At the same time, image edge is fuzzy in dark transcendental image haze removal algorithm. Bilateral filtering is adopted in this paper. Boundary is kept and the noise is removed by the method. The principle is as follows:

$$h(x) = k^{-1}(x) \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(\xi) c(\xi, x) s\left(f(\xi), f(x)\right) \mathrm{d}\xi \,, \tag{7}$$

where $f(x)$ is the input image, $h(x)$ is the output image, $k(x)$ is the normalized parameter, $c(\xi, x)$ is the geometric proximity between the center point x and the collar ξ. Symbol $s(f(\xi), f(x))$is the photometric similarity between the center point x in the metric field and the adjacent ξ pixels.

Transmission rate is estimated by bilateral filtering:

$$t(x) = \frac{1}{\omega(x)} \sum_{y \in \Omega(x)} G_{h_{\mathrm{s}}}\left(\|x - y\|\right) \cdot G_{h_{\mathrm{r}}}\left(|I_x - I_y|\right) t_0(x) \,, \tag{8}$$

$$G_{\mathrm{s}}(x) = \mathrm{e}^{-\frac{\|x-y\|^2}{2h_{\mathrm{s}}^2}} \,, \quad y \in \Omega(x) \,, \tag{9}$$

$$G_{\mathrm{r}}(x) = \mathrm{e}^{-\frac{|I_x-I_y|^2}{2h_{\mathrm{s}}^2}} \,, \quad y \in \Omega(x) \,, \tag{10}$$

$$w(x) = \sum_{y \in \Omega(x)} G_{h_{\mathrm{s}}}\left(|x - y|\right) \cdot G_{h_{\mathrm{r}}}\left(|I_x - I_y|\right) \,, \tag{11}$$

where $t_0(x)$ is preliminary transmittance estimate, calculated by dark transcendental image haze removal algorithm, $\Omega(x)$ represents the region of dark color located in the center x, I is the image intensity value, $w(x)$ is the normalized coefficient, $G_{h_{\mathrm{s}}}$ and $G_{h_{\mathrm{r}}}$ are the Gaussian function.

3.3. The fusion image restoration

In order to eliminate uneven brightness caused by bilateral filtering, the image white balanced are used. Image fusion is carried out by normalized weight in the cross region:

$$J_{\mathrm{s}}(x) = \frac{I(x) - A}{\min\left(\frac{K \cdot \max(t(x), t_0)}{|I(x) - A|}, 1\right)} + A \,, \tag{12}$$

$$J_{\mathrm{d}}(x) = \frac{I(x) - A}{\max\left(t(x), t_0\right)} + A \,, \tag{13}$$

$$J(x) = (1-\alpha)J_{\mathrm{S}}(x) + \alpha J_{\mathrm{d}}(x)\,, \tag{14}$$

where $J(x)$ denotes the recovered image, $J_{\mathrm{d}}(x)$ is the haze removal equation in non-sky area and cross region, $J_{\mathrm{s}}(x)$ is the haze removal equation in sky area and cross region, and $\alpha = 0.35$.

3.4. Contrast limited adaptive histogram equalization

Contrast limited adaptive histogram equalization (CLAHE) is a method to improve image contrast by limiting the height of local histogram. Haze is removed by image contrast improving. The atmospheric light is increased with the linear distance increasing. However, the region average t in the image is affected seriously because of haze. Assume that the brightness in haze regions is larger than in no-haze regions. Before the image enhancement, the input image can minus the average brightness to improve the contrast in haze area.

$$L(x,y) = \gamma(I(x,y) - \bar{I})\,, \tag{15}$$

where $\bar{I}$ is the average brightness, and $\gamma = 2.5$ is used to increase the brightness. Furthermore, γ can be modified in (15) as $\gamma = 2(0.5 + \bar{I}$. It is associated with the image average brightness.

The main steps of CLAHE algorithm are:

(1) Blocking: the input image is segmented into non-overlapping sub-block.

(2) Compute the histogram

$$H_{i,j}(n) = \frac{N-1}{M}\sum_{k=0}^{n} h_{i,j}(k)\,, \tag{16}$$

where M is the number of pixels and N is the grey degree scale.

(3) Compute the limit function

$$\beta = \frac{M}{N}\left(1 + \frac{\alpha}{100}(S_{\max}+1)\right)\,. \tag{17}$$

Here, sub-block histogram is truncated and redistributed according to β, $S_{\max}$ is the maximum slope, and α is truncated coefficient.

(4) Pixels redistributing: calculate the total pixel points out of the limit function N_{tot}. The average gray level can be divided into the shear pixel $A_{\mathrm{vc}} = N_{\mathrm{tot}}/N$. Then, $h_{i,j}(k)$ is sub-block histogram and $f_{i,j}(k)$ is the contrast limited histogram. When $h_{i,j}(k) > \beta$ or $h_{i,j}(k) + A_{\mathrm{vc}} > \beta$, then $f_{i,j}(k) = \beta$. Otherwise, $f_{i,j}(k) = h_{i,j}(k) + A_{\mathrm{vc}}$.

(5) Histogram equalization: the histogram equalization are performed again for the results of step (4) .

4. Discussion of experimental results

To verify the algorithm proposed in this paper, a haze image is dealt with by dark transcendental image haze removal algorithm and the algorithm proposed in this paper. Haze removal effect is compared between them. The simulation environment is: Win7, i7-3610QM, 4GB memory, MATLAB version R2012bs.

Fig. 1. Comparison of the effect of haze removing: up–original image, bottom left–dark transcendental image haze removal algorithm, bottom right–algorithm in this paper

Table 1. Comparison of running time of different methods

	He's method	Method in this paper
Figure 1 running time (s)	2.878068	2.693866
Figure 1 running time (s)	2.842823	3.080598

Figures 1 and 2 are the images dealing with comparing He's algorithm and the algorithm in this paper respectively. According to the image quality assessment (index variance, average gradient and information entropy), He's algorithm and our algorithm are compared in stability, efficiency and haze removing final effect. The larger the image variance is, the richer the image gray levels are. The average gradient is larger and the information entropy is greater. From Tables 1 and 2 we can see that the algorithm proposed in this paper is better in haze image restoration.

Fig. 2. Comparison of haze removing effect: up–original image, bottom left–dark transcendental image haze removal algorithm, bottom right–method in this paper

Table 2. Comparison of image performance parameters

	Variance	Mean gradient	Information entropy (bit)
Fig. 1 up	435.63	2.5843	6.1784
Fig. 1 bottom left	876.403	3.5761	6.4852
Fig. 1 bottom right	3334.1	10.9386	7.6064
Fig. 2 up	407.00	2.5951	5.9194
Fig. 2 bottom left	1103.3	4.1668	6.8753
Fig. 2 bottom right	1765.4	8.5532	7.3683

5. Conclusion

In the dark channel prior haze removal algorithm, the treatment process is slow and sky area is easy to be distorted. In order to solve the problems above, a dark channel prior haze removal algorithm based on adaptive threshold segmentation is proposed. The picture is dived firstly and processed separately by adaptive threshold segmentation. As a result, sky area distorted can be solved. The amount of calculation algorithm is reduced significantly by using bilateral filtering optimizing transmittance. The recovered image is enhanced by limit contrast adaptive histogram equalization, so the image visual effect is improved. However, the algorithm proposed in this paper is not very stable and needs to be further improved.

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Received April 30, 2017