Fog Removal from Color Images using Contrast Limited Adaptive Histogram Equalization

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Abstract—**The images degraded by fog suffer from poor contrast. In order to remove fog effect, a Contrast Limited Adaptive Histogram Equalization (CLAHE)-based method is presented in this paper. This method establishes a maximum value to clip the histogram and redistributes the clipped pixels equally to each gray-level. It can limit the noise while enhancing the image contrast. In our method, firstly, the original image is converted from RGB to HSI. Secondly, the intensity component of the HSI image is processed by CLAHE. Finally, the HSI image is converted back to RGB image. To evaluate the effectiveness of the proposed method, we experiment with a color image degraded by fog and apply the edge detection to the image. The results show that our method is effective in comparison with traditional methods.**

Keywords- CLAHE, fog, degraded, remove, color image, HSI, edge detection.

I. INTRODUCTION

The contrast of images in fog is often affected by optical scattering of light. And the light reaching the human eye is extremely scattered by fog. Increase in scene depth made the contrast degrade exponentially. Poor visibility for many outdoor surveillance systems in fog is a major problem which is difficult to resolve.

Image contrast enhancement is an effective solution to remove fog effects. At present, the image contrast enhancement algorithms can be divided into two types. One is model-based, and the other is non-model-based.

There have been some noticeable model-based approaches. Narasimhan etc.[1] address the problem of restoring the contrast of atmospherically degraded images and video. Then they present methods to locate depth discontinuities and to compute structure of a scene, from two images captured under different weather conditions. Narasimhan etc.[2] develop a general chromatic framework for scene understanding from images taken under poor weather conditions. Schechner etc.[3] present an approach for easily removing the effects of haze from passively acquired images. The approach is based on the fact that usually the natural illuminating light scattered by atmospheric particles is partially polarized. They obtain a great improvement of scene contrast and correction of color. Narasimhan etc.[4] address the question of deweathering a single image using simple additional information provided interactively by the user. They exploit the physics-based models described in prior work and develop three interactive algorithms to remove weather effects from, and add weather effects to, a single image. They demonstrate effective color and contrast restoration using several images.

Recently, Robby T. Tan[7] develops a method that only requires a single input image. A cost function is adopted in the framework of Markov random fields. The method is applicable for both color and gray images. Robby T. Tan etc.[8] propose a method principally using color and intensity information. It enhances the visibility after estimating the color of skylight and the values of airlight.

Dongjun Kim etc.[9] propose to estimate the airlight using cost function, which is based on human visual model, and generate airlight map by modeling the relationship between coordinates of image and airlight. Blurred image due to fog is restored by subtracting airlight map from degraded image.

The most common non-model-based algorithms are histogram equalization and its variations such as histogram equalization(HE), local histogram equalization(LHE) and adaptive histogram equalization(AHE). Pizer etc.[10] propose the Contrast Limited Adaptive Histogram Equalization (CLAHE) method. CLAHE limits the noise enhancement by establishing a maximum value. It has been successfully applied to the medical imaging area. However, there are only few works on degraded color images using CLAHE.

In this paper, we present a CLAHE-based method to restore fog-degraded color images. Any predicted weather information is not required in this method. First, the color images captured by camera in foggy conditions are converted from RGB color space to HSI color space. The reason of conversion is the HSI represents colors similarly how the human eye senses colors. Second, the intensity component of the image is processed by CLAHE. The hue and saturation are unchanged. Finally, the image processed in HSI color space is converted back to RGB color space.

The rest of the paper is structured as follows: In Section II, the RGB color space, HSI color space and conversion between them are introduced in this section. In Section III, the proposed method in this paper is described in detail. The Contrast Limited Adaptive Histogram Equalization(CLAHE) method is explained principally because it is the core of our method; In Section IV, the experimental results are obtained by

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matlab; Finally, the conclusion and discussion are presented in section V.

II. COLOR SPACE

In most cases, the color images captured by camera are in RGB color space. However, the RGB images are difficult to process. So the fog-degraded images are converted form RGB to HSI in this paper. The conversion formulas are presented in this section.

A. RGB Color Space

The RGB color space is any additive color space based on the RGB color model. It is defined by the three chromaticities of the red(R), green(G) and blue(B) additive primaries, and can produce any chromaticity that is the triangle defined by those primary colors.

B. HSI Color Space

The HSI color space is very important and attractive color model for image processing applications because it represents colors similarly how the human eye senses colors. The HSI color model represents every color with three components: hue (H), saturation (S) and intensity (I).

The Hue component describes the color itself in the form of an angle between [0,360] degrees. 0 degree mean red, 120 means green 240 means blue. 60 is yellow, 300 is magenta. The Saturation component signals how much the color is polluted with white color. The Saturation range is [0,1].The Intensity range is between [0,1] and 0 means black, 1 means white.

C. Color Conversion

The conversion formulas of color images from RGB to HSI [11]are given by

$$
\begin{aligned}
I &= \frac{R+G+B}{3} \\
H &= \frac{1}{360}\left[90-\arctan\left(\frac{2R-G-B}{\sqrt{3}(G-B)}\right)+\{0,G>B;180,G<B\}\right] \quad (1) \\
S &= 1-\frac{\min(R,G,B)}{I}
\end{aligned}
$$

On the contrary, the conversion formula of color images from HSI to RGB[12] is given by

For $0^\circ \le H < 120^\circ$,

$$
\begin{aligned}
R &= \frac{I}{\sqrt{3}}\left[1+\frac{S\cos(H)}{\cos(60^\circ - H)}\right] \\
B &= \frac{I}{\sqrt{3}}(1-S) \\
G &= \sqrt{3}I - R - B
\end{aligned} \tag{2}
$$

For $120^\circ \le H < 240^\circ$,

$$
\begin{aligned}
G &= \frac{I}{\sqrt{3}}\left[1+\frac{S\cos(H-120^\circ)}{\cos(180^\circ - H)}\right] \\
R &= \frac{I}{\sqrt{3}}(1-S) \\
B &= \sqrt{3}I - R - G
\end{aligned} \tag{3}
$$

For $240^\circ \le H < 360^\circ$,

$$
\begin{aligned}
B &= \frac{I}{\sqrt{3}}\left[1+\frac{S\cos(H-240^\circ)}{\cos(300^\circ - H)}\right] \\
G &= \frac{I}{\sqrt{3}}(1-S) \\
R &= \sqrt{3}I - R - G
\end{aligned} \tag{4}
$$

III. PROPOSED METHOD

There have been some image contrast enhancement methods. For example, adaptive histogram equalization is a effective method. It divides an image into regions and selects a sliding window. The sliding window is processed by means of local histogram equalization. AHE can enhance the contrast of each region. AHE is applied widely and demonstrated effectively. However, slow speed and the enhancement of noise in relative homogeneous regions are two problems.

A. Contrast Limited Adaptive Histogram Equalization

When the relative region is fixed, the local histogram of a pixel is the same as the pixel which is in the center of the Rectangular Window. Only the pixels within the local area are considered, others are neglected. But according to the characteristic of human vision, the visual systems change with the relative region and they are affected by the surrounding environment.

To solve these problems, S.M. Pizer proposed a method which is called contrast limit Adaptive histogram equalization (CLAHE). The CLAHE method applies histogram equalization to a contextual region. Each pixel of original image is in the center of the contextual region. The original histogram is clipped and the clipped pixels are redistributed to each gray-level. The new histogram is different with ordinary histogram, because each pixel intensity is limited to a user-selectable maximum. So CLAHE can limit the noise enhancement.

The CLAHE method can be divided into steps to achieve.

$$
N_{aver} = \frac{N_{CR-Xp} \times N_{CR-Yp}}{N_{gray}} \tag{5}
$$

Where: N_{aver} is the average number of pixel;

N_{gray} is the number of the gray levels in the contextual region;

N_{CR-Xp} is the number of pixels in the x dimension of the contextual region;

N_{CR-Yp} is the number of pixels in the y dimension of the contextual region.

Base on the Eq.(5), the N_{CL} can be calculated by the equation:

$$N_{CL} = N_{clip} \times N_{aver} \tag{6}$$

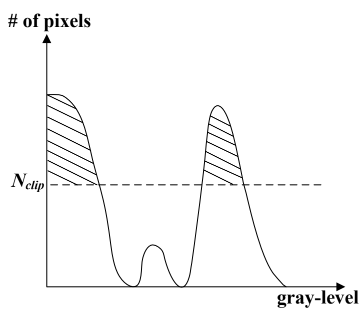
Where: N_{CL} is actual clip-limit.

N_{clip} is the maximum multiple of average pixels in each gray level of the contextual region.

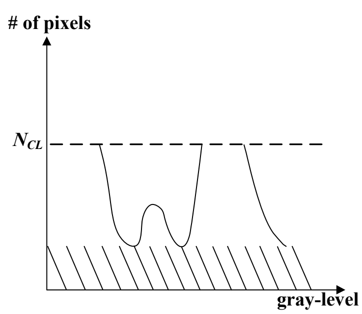
The original and clipped histograms are shown in Figure 1. In Figure 1.a, if the number of pixels is greater than N_{clip}, the pixels will be clipped. We defines the total number of clipped pixels as $N_{\Sigma clip}$, then the number of pixels distributed averagely into each gray level is given by

$$N_{acp} = \frac{N_{\Sigma clip}}{N_{gray}} \tag{7}$$

$H_{CR}(i)$ is the number of pixels in each gray level of the contextual region , i is the number of gray level.



(a) Original histogram



(b) Clipped histogram

Figure 1. Original and clipped histograms

Base on the above equations, we can calculate the contrast limited histogram of the contextual region, the rules are given by:

$$\begin{aligned}&If \quad H_{CR}(i) > N_{CL}, \quad H_{NCR}(i) = N_{CL};\\&Else\ if \quad H_{CR}(i) + N_{acp} \geq N_{CL}, \quad H_{NCR}(i) = N_{CL};\\&Else \quad H_{NCR}(i) = H_{CR}(i) + N_{acp}\end{aligned} \tag{8}$$

After the above distribution, the remaining number of clipped pixels is expressed by N_{LP} , then the step of distributed pixels is given by

$$S = \frac{N_{gray}}{N_{LP}} \tag{9}$$

The program starts search according to the above step from the minimum to the maximum of gray level. If the number of pixels in the gray level is less than N_{CL}, the program will distribute one pixel to the gray level. If the pixels are not all distributed when the search is end, the program will calculate the new step according to Eq.(9) and start new search until the remaining pixels is all distributed. Then, the new histogram in Figure 1.b is achieved.

Step 4 The gray level histogram which is limited contrast in each contextual region is processed by histogram equalization.

Step 5 The points in the center of the contextual region are regarded as the sample points.

Step 6 The result mapping at any pixel is interpolated from the sample mappings at the four surrounding sample-grid pixels. Figure 2 shows the location between sample points and evaluation point. If the pixel mapped is at location (x, y), the intensity is i , m_{+-} , m_{++} , m_{-+} and m_{--} is respectively the upper right pixel, lower right pixel, lower left pixel and upper left pixel of (x, y). Then the interpolated AHE result is given by

$$\begin{aligned}m(i) = {}& a\left[bm_{--}(i) + (1-b)m_{+-}(i)\right]\\&+ [1-a][bm_{-+}(i) + (1-b)m_{++}(i)]\end{aligned} \tag{10}$$

Where:

$$a = \frac{y - y_-}{y_+ - y_-} \ , \ b = \frac{x - x_-}{x_+ - x_-}$$

Pixels in the borders of the image outside of the sample pixels need to be processed specially. We can use linear interpolation of the mappings at the two closest points or , in the corners where there is only a single close sample pixel, application of only one mapping[10].

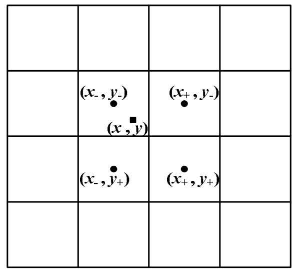


Figure 2. Sample points(●) and evaluation point(■)

B. Fog Removal

We apply the following simple method to remove fog effect from a color image. First, a color image degraded by fog is inputted; Second, the original image is converted from RGB color space to HSI color space; Third, the intensity(I) component is processed by the CLAHE-based method. The hue(H) and saturation(S) components is unchanged. And then a new HSI image is obtained. Finally, we convert the new HSI image to the RGB image which is the result.

IV. EXPERIMENTAL RESULTS

In order to evaluate the effectiveness of the proposed method, we experiment with a fog-degraded image in real scenes and apply the edge detection to the image. Figure 3.a shows the original image captured in foggy conditions. As can be seen form figure, the contrast is poor and the detail is blurry. The middle building covered with fog is dim. Figure 3.b shows the result by global histogram equalization. The sky region is enhanced overly and the middle building is still blurry. Figure 3.c shows the result by our method, in contrast to (a) and (b), the image definition is much better. The middle building is clearer than original image. And the building roof has more outline information.

In Figure 4, the results of the edge detection of the images in Figure 3 are obtained. The Sobel method is used and the threshold value is 0.02. Figure 4.a shows the edge detection result of original image. Most of the edge information of the middle building is lost. Figure 4.b shows the edge detection result of Figure 3.b. The edge information is more than the original image. But the edge information of the middle building is only a small part. Figure 4.c shows the edge detection result of Figure 3.c, in contrast to (a) and (b), the edge information of the middle building is much more. Especially, the edge information of the roof of building is achieved.

V. CONCLUSION AND DISCUSSION

In this paper, we present a CLAHE-based method to remove fog effects from a single color image. Any prior weather information is not required. The CLAHE-based method can limit the enhancement of the noise effectively and enhance the details of the images obviously. So we apply the method to the image captured in the real foggy conditions. In this approach, processing is done in HSI color space. At last, the image is converted back into RGB color space. To evaluate the performance of our method, we experiment with fog-degraded color images. The experimental results show that a significant improvement in image contrast enhancement of fog-degraded images. In comparison with other methods, our method is more simple and faster. In addition, the effect of our method is satisfactory. The images processed by our method are single static color images. In the future, our research will be focused on fog removal from video sequences.

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(a)Original fog-degraded image (b) Result by global histogram equalization (c) Result by our method

Figure 3. Results by HE and our method

(a) Edge detection result of Fig.3.a (b) Edge detection result of Fig.3.b (c) Edge detection result of Fig.3.c

Figure 4. Results by the edge detection based on Sobel method (THRESH=0.02)