Image Haze Removal Using Dark Channel Prior based on Guided Image

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Abstract. In foggy weather, the interference of fog has a serious impact on the accurate monitoring of vehicle targets. To address this problem, this paper proposed a method which is image haze removal based on the guided image. In the process of this method, the clear images are as the guide images, which is designed to effectively redress the bright region which is not meet the dark color prior by the prior information of the guide image, to avoided the error estimates of this kind of area of transmissivity. Experimental results demonstrate that our method achieves significant improvement in both image quality and image detail when compared with classical image haze removal method.

1. Introduction
Chongqing is a famous foggy city. The monitoring system of highways cannot accurately monitor running vehicles within low contrast due to atmospheric scattering in the foggy weather. Therefore, simple and effective image haze removal method is of great significance to improve the accuracy of the highway monitoring system.

At present, there are two main types of image haze removal methods. One of methods is based on image filter [1-3], for example, guided image filter is a popular algorithm. Filtering the image directly without obtaining atmospheric condition information can’t achieve satisfactory results, because image contrast is closely related to atmospheric condition information. The other one is based on the physical model of atmospheric scattering [4], which is a haze removal model using the law of atmospheric scattering. This method is able to take advantage of prior knowledge of weather conditions to process images and enhance low-contrast images accurately. However, the abovementioned method has some obvious disadvantages. Images are taken by monitoring system usually do not have any information on depth of field and atmospheric conditions causing uncertainty in the image haze effect. To this end, scholars have studied the method based on statistical haze removal methods [5, 6], and achieved insightful findings which require adequate and accurate color information and variability. When the haze is very dense, the color is very thin and the difference is not obvious enough, therefore the estimated transmissivity of this method is not reliable [4]. In order to overcome these limitations, reference [7] has proposed a simple and effective dark channel prior image haze removal method based on the statistical law of the haze-free image database, which achieved a good effect on these images, but this algorithm is based on the assumption of the dark channel. When the bright region of this hypothesis is not satisfied, the estimated transmissivity of the algorithm is too small, and the recovery result does not achieve satisfactory results. Therefore, in view of the above problems, this paper proposes an image haze removal method that makes full use of prior information based on the information of the guided image and the dark channel prior haze removal model.
2. The model of haze removal using dark channel prior [7]

In the imaging model, the formula of an atomization image is described as following:

\[
I(x) = J(x)t(x) + A(1-t(x))
\]

where, \(I\) is the observed image, \(J\) is the scene radiance, \(A\) is the global atmospheric light, and \(t\) is the medium transmission describing the portion of the light that is not scattered and reaches the camera. The main goal of the haze removal method is to recover \(J\) from \(I\).

The dark channel prior is the conclusion obtained by statistical analysis of a large number of haze-free images. In many local areas of an image, some pixels have at least one color channel with a small value. Therefore, the minimum value of the scene radiance in this area should be small. For images, the following formula can be represented:

\[
J_{\text{dark}}(x) = \min_{c \in (r,g,b)} \left( \min_{y \in J(x)} \left( J'(y) \right) \right),
\]

where, \(J'\) is a color channel of \(J\), and \(\Omega(x)\) is a local patch centered at \(x\). According to statistical knowledge, the intensity of \(J_{\text{dark}}\) is small and tends to be zero, if \(J\) is a haze-free outdoor image, and so, \(J_{\text{dark}}\) is defined as the dark channel of \(J\), subsequently the above statistical observation or knowledge is called the dark channel prior.

From the above description, it is assumed that the global atmospheric light \(A\) is given, and assumed that the transmissivity in the local region is constant. Taking the minimize operation in the local channel on the haze image, so that equation (1) can be obtained as follows:

\[
\min_{y \in J(x)} \left( \frac{I'(y)}{A'} \right) = t(x) \min_{y \in \Omega(x)} \left( \frac{J'(y)}{A'} \right) + \left( 1 - t(x) \right),
\]

Then, we take the minimize operation with the three color channels on the above equation and obtain:

\[
\min_{c} \left( \min_{y \in J(x)} \left( \frac{I'(y)}{A'} \right) \right) = t(x) \min_{c} \left( \min_{y \in \Omega(x)} \left( \frac{J'(y)}{A'} \right) \right) + \left( 1 - t(x) \right),
\]

According to the statistics knowledge of the dark channel prior, in the haze-free image, the dark channel prior \(J_{\text{dark}}\) of the image is closed to zero, which can be expressed as following:

\[
J_{\text{dark}}(x) = \lim_{\Omega(x)} \left( \min_{c \in (r,g,b)} \left( \min_{y \in \Omega(x)} \left( \frac{J'(y)}{A'} \right) \right) \right) = 0,
\]

Since the atmospheric light factor is constant, \(A \neq 0\). Therefore, substituting into formula (5) to the following formula:

\[
\lim_{\Omega(x)} \left( \min_{c \in (r,g,b)} \left( \min_{y \in \Omega(x)} \left( \frac{J'(y)}{A'} \right) \right) \right) = 0.
\]

Substituting formula (6) into formula (4) and then simplifying, and the derived equation can be expressed as:

\[
\bar{t}(x) = 1 - \min_{c \in (r,g,b)} \left( \min_{y \in \Omega(x)} \left( \frac{J'(y)}{A'} \right) \right),
\]

In order to avoid the decreasing in the image quality caused by the foggy image, a constant \(\omega(0 < \omega < 1)\) is added to the formula (7) listed in the literature [7], subsequently the formula (7) is represented as the following form:

\[
\hat{t}(x) = 1 - \omega \min_{c \in (r,g,b)} \left( \min_{y \in \Omega(x)} \left( \frac{J'(y)}{A'} \right) \right),
\]

(8)
In the reference [7], the soft matting algorithm [8] is applied in the transmittance function \( t(x) \) in order to improve the results. Therefore, the haze removal model can be obtained by the above descriptions as shown in the following formula:

\[
J(x) = \frac{I(x) - A}{\max(t(x), t_0)} + A
\]

(9)

In addition, the \( t_0 \) is usually set to be 0.1. First, select the pixel with the largest gray value of 0.1% in \( J_{\text{dark}} \), and then compare the maximum value of these pixels in the original image I as the value of A listed in the formula(9).

Using the above model to process the foggy image in the highway monitor, the results are shown in Figure 1.

![Figure 1](image1)

Figure 1. (a) and (b) are the initial image and the experimental result respectively.

It can be seen from the results in Figure. 1 that the above algorithm can yield better results, and the sharpness of the picture is quite high, but the vehicle license plate number information is blurred, and the monitoring of the vehicle does not achieve satisfactory results. Therefore, it is necessary to improve the above haze removal algorithm in order that the processing result can meet the monitor expectation.

3. Image Haze Removal Using Dark Channel Prior based on Guided Image

It can be seen from the results of Figure. 1 that the haze removal using dark channel prior results in some details in the image to be lost, and the information in some areas is significantly missing which is due to the large area of bright areas, because the highway is essentially a large white area. In the foggy environment, the pixel values of these areas are also much larger than those of other areas. It is difficult to find dark prior points with a pixel point of 0 in these areas, which makes the dark prior assumption unreasonable in these areas. In order to overcome this shortcoming, this paper uses the information of the guided image as the dark prior hypothesis, that is, the guided image is the dark channel image of the haze-free image, and replaces this guide map with \( t(x) \) in the formula (9).

3.1 The dark channel image of guided image

We use the dark channel image of the haze-free image as the guided image, which is the gray image composed of the minimum values of the three channels of RGB of the image, and then the image obtained by filtering the minimum value. Figure.2 and 3 show dark channel image results and histogram comparisons. The results are presented as follows:
Figure 2. (a) and (b) are dark channel images of foggy and haze-free images, respectively.

Figure 3. Histogram comparison of two dark channel images

It can be seen from the dark channel diagram of Figure 2 that the dark channel image of the fog image shows a certain gray color, while the fogless image is a large amount of black (the pixel is close to 0). And it can be seen from the histogram of Figure 3 that most of the pixels of the dark channel image of the haze-free image are concentrated between the interval values of [0, 50], therefore, it is justified that using the dark channel image of the haze-free image as the guided image.

3.2 Guided image filtered image results

According to the description of the above chapters, it is reasonable to assume that the dark channel image of the haze-free image is used as the dark prior. Therefore, we replace t(x) in the haze removal model formula (9) with a dark channel image of the haze-free image. The experimental results are shown in Figure 4 below.

Figure 4. (a) and (b) are haze removal images and transmissivity images

It can be seen from the results in Figure 4 that the improved algorithm can obtain better results, especially the details of the vehicle information are well preserved and clearer, which is beneficial to
the subsequent vehicle monitoring work. Therefore, using the dark channel image of the guided image as a dark prior hypothesis can help to protect the image detail information.

4. Analysis of results
All the experimental images in this paper are collected from the Chongqing highway monitor. The size is uniformly cut to 800*337, and the guided images used are all haze-free images of the corresponding scenes (because the images are collected from monitor, which exist in both foggy and haze-free environments). The model is solved using Matlab 2012b, the processor is Intel i7-9820X, memory 16G, DDR4.

In order to further verify the effectiveness of the presented method, the paper compares the experimental results of the two methods with several indexes of image information. It mainly includes: entropy (EN), peak signal-to-noise ratio (PSNR), edge gradient ratio (QF) and average gradient (AVG). Subsequently, we use these indexes to analyze the experimental results of the two methods, in which we separately processed 20 fog images, and finally obtained the average value of each index for analysis and comparison. The specific results are shown in Tables 1, 2, 3 and 4.

(1) Entropy (EN): Indicates the amount of average information contained in an image. The larger the value, the more information is contained. The results are shown in Table 1 below.

| Method         | EN   |
|----------------|------|
| Classical method | EN = 7.1214 |
| Our method     | EN = 7.5127 |

(2) Peak signal-to-noise ratio (PSNR): The higher the PSNR, the better the processing effect and quality.

| Method         | PSNR  |
|----------------|-------|
| Classical method | PSNR = 57.8991 |
| Our method     | PSNR = 61.9881 |

(3) Edge gradient ratio (QF): Evaluate edge or gradient quality, the larger the edge, the more obvious.

| Method         | QF   |
|----------------|------|
| Classical method | QF = 4.9603 |
| Our method     | QF = 8.8810 |

(4) Average Gradient (AVG): Also known as sharpness, it reflects the small detail contrast and texture variation features in the image, and also reflects the sharpness of the image. The value is bigger more than better.

| Method         | AVG  |
|----------------|------|
| Classical method | AVG = 8.6390 |
| Our method     | AVG = 11.4728 |

Integrating the above results, it can be seen from Figure 5 that the method is superior to the traditional method in several index values.
It can be seen from the above results that the preservation of the gradient details of the processed image is more perfect, therefore the integrity of the detailed information of the vehicle can be, which facilitate in monitoring the vehicle of the highway, and improving the recognition of the target information of the vehicle accuracy.

5. Conclusion
Aiming at the problem of vehicle monitor on highways in foggy weather, this paper presented a method, named as image haze removal, using dark channel prior based on guided image. The haze-free image is used as the guided image, that is, the dark channel image of the haze-free image is used as the dark prior information, which replaces the prior information obtained by the mapping algorithm in the conventional method, therefore the haze removal of the fog image can be achieved.

The experimental results demonstrated that the method effectively improves the retention and integrity of the detailed information in the image and improves the accuracy of vehicle monitor. Since the method is implemented under the condition that the haze-free image is needed as a priori information, the future work should focus on the improvement of the model for this situation, and improve the adaptability and unsupervised of the method.

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