Single Image Defogging Algorithm Based on Sky Region Segmentation

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Abstract. The visibility, contrast and color fidelity of images acquired under foggy weather will decrease to a certain extent, image defogging is an important part of image processing. Since the dark channel prior is not applicable to the sky area, which results in the color distortion and some noise of the restored fog-free image. Based on the segmentation of the sky region, it is proposed to separately estimate the atmospheric light value and transmission map according to different regions, and finally generates a defogging image using the optimized synthetic global map. In order to divide the sky domain and the non-sky domain more accurately, the two results obtained by the threshold segmentation method for the dark channel map and the improved threshold segmentation method for the original foggy image are considered at the same time. In the step of estimating the transmittance of the sky domain, the dark channel map of sky domain is obtained based on HSI color space, making the sky area more natural after defogging.

Experimental results show that the algorithm can achieve good defogging effect, smooth edge transition between regions, and the defogging images are more natural and clear.

1. Introduction
As an important means and approach to utilize and obtain visual information, images are the objective performance of natural scenery and are called the basis of vision. The quality of the image has a profound impact on the subsequent interpretation, analysis, recognition by humans or machines. For images taken in foggy conditions, the color distortion and the loss of information will bring certain difficulties to solve practical problems in computer vision and other fields. Therefore, it is necessary to perform image defogging processing on the haze image to enhance the visual effect of the image.

At present, the processing methods for foggy images are mainly divided into two categories: methods based on image enhancement and methods based on image restoration. The method based on image enhancement does not consider the cause of image degradation. By enhancing the useful information of the image globally or locally, there are many image enhancement methods that can be used for foggy images. The approaches based on image enhancement can be roughly divided into four categories: method based on gray level correction [1,2], method based on image enhancement [3], method based on wavelet transform [4] and method based on atmospheric modulation function [5]. The method based on gray level correction [1,2] has simple algorithm, small calculation amount and high efficiency, but there is a phenomenon of local blocking. The defogging method based on image sharpness [3] has the advantage of clear physical meaning and easy implementation, but the image enhanced by this algorithm has halo phenomenon, which cannot ensure color fidelity. Based on wavelet transform [4], the details of image defogging in brighter areas are very prominent, but this method is still not very prominent in dealing with the details of darker image parts. The method based on atmospheric modulation function
[5] approximates the degradation process of the image quality by the prediction of the atmospheric modulation transfer function. However, compared with other approaches, it is relatively unstable and difficult to apply.

The method based on image restoration starts from the physical model of image degradation, and obtains the relevant parameters of each degradation link by analyzing and solving the inverse process of the image degradation process, so as to restore as vivid and clear images as possible. Tan et al. [6] modeled the ambient atmospheric light and used the MRF model to improve the local contrast of the scene image, thereby recovering the fog-free image. However, this method also has certain limitations. The processed image is often too saturated in color. Fattal et al. [7] proposed an accurate image defogging model, but this method requires sufficient color difference in the foggy degraded image and it will fail when processing images affected by higher fog concentrations. He et al. [8] did a lot of research and statistics on outdoor fog-free images, and proposed a dark channel algorithm to achieve the defogging effect and achieved good defogging effects, but there is an inaccuracy for its bright sky areas in foggy images in this image fog removal algorithm.

Therefore, this paper proposes a single image defogging algorithm based on sky region segmentation to solve the problem of color distortion and noise when using dark channel prior conditions to defog the sky area. The main contribution of this paper is shown as follows: (1) Based on the initial segmentation results of threshold segmentation of the dark channel image, the improved threshold segmentation algorithm is used to segment the foggy image to realize the precise division of the sky domain and the non-sky domain. (2) This algorithm estimates the atmospheric light map and transmission map for different areas respectively. The maps of different regions are synthesized and optimized to generate a global map, and a natural and clear defogging image is generated according to the atmospheric scattering model.

2. Materials and Methods
In this study, we adopted a hybrid method including three different stages. In the first stage before the defogging procedure, the image is divided into sky and non-sky areas. In the second stage, the atmospheric light map and transmission map are estimated for the sky and non-sky areas respectively. After that, the two regions are synthesized and optimized to generate the final global atmospheric light map and global transmission map. Finally, in the third stage, a natural and clear dehazing image is generated based on the atmospheric scattering model. The overall flow chart of this paper is shown in Figure 1.

2.1. Dark channel prior principle
He et al. [8] found that for most non-sky areas, there is at least one pixel with a very low color channel value, which is close to zero, based on a large number of statistics on fog-free images. The dark channel prior knowledge can be expressed as:

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

Where, $J$ represents any haze-free image, $J^c$ represents each color (RGB) channel of the color image $J$, and $\Omega(x)$ represents the local window neighbourhood centered on $x$. And $J$ is close to 0.

2.2. Extract and Segment the Sky Region
Otsu algorithm is an adaptive threshold determination algorithm, which gives the best threshold of separation between classes by gray value, and divides the image into a background area $A_{bg}$ and a target area $A_{tar}$, as shown in equation (2).

$$M(x) = \begin{cases} A_{tar}, & p_i > T_o \\ A_{bg}, & p_i < T_o \end{cases}$$ (2)
Where, \( p_i \) represents the grayscale pixel value of the input image, \( T_0 \) represents the best threshold of Otsu algorithm.

For some foggy images, the gray scale difference between the background area and the target area is small, and the Otsu algorithm will cause errors in image segmentation. Therefore, this paper corrects the threshold \( T_0 \) and re-establishes the optimal segmentation threshold \( T \). The modified optimal threshold \( T \) is defined as:

\[
T = \frac{T_0 + k_L L}{1 + k_L}
\]  

(3)

Where, \( L \) is the average pixel value of the brightest 1% of the dark channel map of the input image, \( k_L \) is the threshold’s degree of correction, the larger the \( k_L \), the greater the \( T \) is affected by \( L \), the deeper the correction. In the experiment of this paper, the value of \( k_L \) is 2. This algorithm that uses \( T \) as the segmentation threshold is the so-called improved Otsu algorithm.

This research is based on the Otsu algorithm segmentation result for the dark channel map and the improved Otsu algorithm segmentation result for the foggy image, the overlapping sky area in the two segmentation results is regarded as the sky domain. In order to make the transition between the sky region and the non-sky region more coherent, the binary segmentation result is subjected to morphological erosion operation. In order to obtain the detailed information of the image edge, the result of the morphological erosion operation is subjected to a guided filtering operation to obtain the final refined segmentation result.

2.3. Atmospheric light value estimation

2.3.1 Atmospheric light value evaluation of global area. To estimation the atmospheric light value evaluation of full-frame image, the dark channel map of the global foggy image is obtained first, then the top 0.1% pixels with the largest brightness value are selected and the positions of these pixels are recorded, finally, the largest brightness value among them is determined to be the atmospheric light value \( A_{\text{global}} \).
2.3.2 Atmospheric light value evaluation of sky area. Similar to the steps in section 2.3.1, to estimation the atmospheric light value evaluation of sky area, obtain the dark channel map of the sky areas first, compare and select the largest brightness value among the top 0.1% brightest pixels as the atmospheric light value $A_{sky}$. It is worth mentioning that the dark channel map of the sky area is obtained by multiplying the global dark channel map and the final binary segmentation result extracted in section 2.2.

$$A = \max( A_{\text{global}}, A_{\text{sky}} )$$

(4)

In order to prevent overexposure, choose the larger one of the atmospheric light value of sky $A_{sky}$ and the global atmospheric light value $A_{\text{global}}$ as the final atmospheric light value $A$.

2.4. Transmittance estimation

2.4.1 Transmittance evaluation of non-sky areas. For non-sky areas, assume that the atmospheric light intensity $A$ is known, and the transmittance $\tilde{t}(x)$ in the neighborhood of the window is a certain fixed value. Then equation (1) can be transformed into:

$$\frac{I^c(x)}{A^c} = \frac{\tilde{I}(x)}{A^c} + 1 - \tilde{I}(x)$$

(5)

Where, $I(x)$ represents a foggy image to be processed, Minimize equation (5) to:

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

(6)

which is:

$$\tilde{I}(x) = \frac{1 - \min_{y \in \Omega(x)} \left( \min_{c} \left( \frac{I^c(y)}{A^c} \right) \right)}{1 - \min_{y \in \Omega(x)} \left( \min_{c} \left( \frac{J^c(y)}{A^c} \right) \right)}$$

(7)

Since $J_{\text{dark}}$ is close to 0, in order to express the depth of field for the image, the coefficient $\omega$ ($0 < \omega < 1$) is introduced by the equation (7), the transmittance of non-sky area can be calculated by the equation (8):

$$t_{\text{no-sky}}(x) = 1 - \omega \min_{y \in \Omega(x)} \left( \min_{c} \left( \frac{I^c(y)}{A^c} \right) \right)$$

(8)

Where, $\omega$ is generally 0.95.

2.4.2 Transmittance evaluation of sky area. Through [9], it is found that for the pixels in the sky area, the values of the R, G, and B components are very large and almost equal. For the sky area of a foggy image, to perform defogging in the HSI color space, we only need to appropriately reduce the value of the I brightness channel, and the saturation S and hue H could remain unchanged.

In order to maintain the consistency of the whole image, the channel I is selected to be processed by the dark channel algorithm.

$$t_{\text{sky}} = 1 - \frac{1 - \min_{y \in \Omega} \left( \min_{c} \left( \frac{I_{\text{sky}}^c(y)}{A^c} \right) \right)}{1 - \eta \min_{y \in \Omega} \frac{I_{\text{sky}}}{A}}$$

(9)
Where, $I_{sky}$ represents the sky area of the input image and $\eta = 0.9$. $t_{sky}$ and $t_{no-sky}$ can synthesize a complete global transmission map $t_{global}$. The final transmission map $t$ is the result of optimization by guided filtering on $t_{global}$.

2.5. Foggy image restoration
At this time, $I$, $A$, and $t$ are all known, and $J$ can be calculated as follows:

$$J(x) = \frac{I(x) - A}{\tilde{t}(x)} + A$$  \hspace{1cm} (10)

It can be seen from equation (10) that when $\tilde{t}(x)$ is too small, the fog-free image $J$ will be too large, so $\tilde{t}(x)$ will set the lower limit to $t_0$ (the value in this paper is 0.1). The final formula for obtaining a fog-free image $J$ is:

$$J(x) = \frac{I(x) - A}{\max(\tilde{t}(x), t_0)} + A$$  \hspace{1cm} (11)

3. Results & Discussion
Foggy images can be divided into two categories according to their characteristics. One is that the area close to the camera is clearer than the far area, and the junction between the sky and the urban buildings on the ground is more blurred. The other type is that the entire image is blurred due to the higher fog concentration, and the color of the entire image is relatively unclear under the influence of fog.

Figure 2. Original images, defogging process and defogging results.
Figure 2 shows original images, the process of defogging and the final defogging results of foggy images with more blurred sky boundaries. Column (b) and (c) in Figure 2 respectively show the threshold segmentation results of the Otsu method and the improved Otsu threshold segmentation results. It is not difficult to see that the improved Otsu method in this paper can well separate the sky and the non-sky domain, which verifies the effectiveness of the proposed threshold segmentation algorithm in this paper. Column (a) and (d) in Figure 2 show the comparison between the original image and the image after defogging. The results show that the restored image can achieve a good defogging effect. There are no obvious color patches in the sky area, and the image is more natural and clear after fog removal. It is very obvious that the fuzzy junction area of buildings and sky has a good effect of fog removal, especially in the middle image and the bottom image.

Figure 3 shows original images, the process of defogging and the final defogging results of foggy images that are globally blurred. In column (d) of Figure 3, it can be seen that the proposed image defogging algorithm has achieved satisfied performance. The image clarity and color accuracy of the defogging images in figure 3 are greatly improved than original foggy images. It is worth mentioning that our algorithm restores the blurred distant mountains to a clear outline in the bottom image, which shows the advantages of our algorithm.

SSIM measures similarity in terms of brightness, contrast, and structure. The value range of SSIM is [0,1] and the larger the value, the smaller the distortion. The SSIM calculated from the defogging images and the original images in Figure 2 and Figure 3 is shown in Table 1. The SSIM in Table 1 indicates that the defogging image has less distortion than the original image. Experiments show that our proposed method has a good effect on image defogging, and can reduce the effect of dark channel method on color distortion and noise.

| Table 1. SSIM calculated from original foggy image and its defogging image |
|---------------------|---------------------|---------------------|---------------------|
| Figure 2 SSIM | Figure 3 SSIM |
| Top 0.8562 | Top 0.8175 |
| Middle 0.8877 | Middle 0.8359 |
| Bottom 0.8259 | Bottom 0.5723 |
4. Conclusions
Because the dark channel a priori is not suitable for the defogging processing of the sky domain, this paper proposes a defogging algorithm for segmentation of the sky area: the threshold optimization of the Otsu algorithm to segment the image can more effectively segment the sky area. By separately calculating and integrating the atmospheric light value and transmittance of different regions, a more detailed transmittance can be obtained, and the restored image error can be lower by setting a lower limit for the transmittance. In the test results, the transition between the regions of the restored image is smooth and natural, and the color distortion and noise are not obvious.

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References
[1] Kim J.Y., Kim L.S., Hwang S.H. (2001) An Advanced Contrast Enhancement Using Partially Overlapped Sub-Block Histogram Equalization. IEEE Transactions on Circuits and Systems for Video Technology, 11(4):475-484.
[2] Stark J.A. (2000) Adaptive image contrast enhancement using generalizations of histogram equalization. IEEE Transactions on Image Processing, 9(5):889-896.
[3] Jobson D.J., Rahman Z, Woodell G.A. (1996) Retinex image processing: improved fidelity to direct visual observation. In: Proceedings of the 1996 Color and Image Conference: Society for Imaging Science and Technology, 124-125.
[4] Fan T, Li C, Xiao M, et al. (2017) An Improved Single Image Defogging Method Based on Retinex. In: International Conference on Image.
[5] Cao Y, Zhang Y. (2014) Wavelet-Based Retinex Algorithm for Image Defogging. Journal of Jiangsu University of Science & Technology.
[6] R. T. Tan. (2008) Visibility in bad weather from a single image. In: 2008 IEEE Conference on Computer Vision and Pattern Recognition, Anchorage. pp.1-8.
[7] R. Fattal. (2008) Single image dehazing. ACM Transactions on Graphics (TOG), 27(3): 1-9.
[8] He K, Sun J, Tang X. (2009) Single Image Haze Removal Using Dark Channel Prior. In: 2009 IEEE Conference on Computer Vision and Pattern Recognition.
[9] Wang X , Shuai G , Hui W , et al. (2016) A fast algorithm for image defogging. In: International Symposium on Advanced Optical Manufacturing & Testing Technologies: Optical Test International Society for Optics and Photonics.