International Journal of Recent Engineering Research and Development (IJRERD)
ISSN: 2455-8761
www.ijrerd.com || Volume 05 – Issue 07 || July 2020 || PP. 01-08

Research on the defogging method based on Sky segmentation

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Abstract: Due to low visibility in foggy environment, machine vision system is extremely vulnerable to the impact of smog and other adverse. This paper proposes a method of defogging based on sky segmentation, after preprocessing the foggy image， the algorithm of OTSU was used to identify the sky region and non-sky region, and the image was divided into sky region and non-sky region, the coefficients of these two region are estimated respectively, a bilateral filter is used to refine the merged transmittance image, finally, the atmospheric scattering model is used to restore the scene brightness. The experimental results show that this method could improve the image information to some extent. It is of great significance to improve the efficiency of machine vision system in fog environment.

Keywords: Visual system，Sky segmentation，Defogging, Transmittance

1. Introduction

In foggy weather, the light of various colors is absorbed and scattered by suspended particles in the atmosphere, resulting in a dusty visual effect, the lower grayscale reflected in the pixel grayscale is extendedand the higher gray value is compressed, the histograms are not evenly distributed, but they're more concentrated, the final result is blurring of the object, loss of informationanddistortion of color, the features of many scenes in the image are also submerged in the fog, which makes it difficult to distinguish and extract, outdoor machine vision systemssuch as video surveillance, intelligent vehicles and navigation tracking based on image feature extraction are damaged extremely.

The influence of haze increases with distance, so image defogging is a challenging field [1]. In the early theories of defogging methods, some researchers propose that the image quality decreases exponentially at the depth point, in order to obtain the structural information of the scene, namely depth clues. In the reference [2], two or more images of the same scene have been taken in different weather environments, which are used to restore fog-free images. This kind of processing method couldn't meet people's needs completely. People put forward an algorithm based on polarization [3] [4], the magnitude of polarization is used to achieve the purpose of defogging. Next, some researchers put forward several successful defogging methods based on the bias theory. Histogram equalization is widely used in image enhancement,by using the principle of histogram equalization of own functions, the goal of histogram distribution equalization is realized,to achieve the goal of histogram distribution equilibrium. However, when the density is uneven and the depth information is unknown, the result could not guarantee the desired enhancement effect of the local region[5]. Su *et al.*[6] proposed a fogging algorithm based on the dark channel image centroid shift,the k-mean algorithm is used to carry out clustering analysis on the dark channel of foggy image,the centroid shift of the dark channel image of each scene is calculated for the transmittance correction of the scene. However, the effect of this method is affected by the number of clusters.Paper [7] estimated the reflectivity to infer the transmittance of reflected light in the air.He *et al.*found an important law: dark channel priori, in the non-sky region without fog, the image is decomposed into a certain number of sub-blocks, it is found that there is a point where the brightness of the color channel tends to 0 in each of the sub block's pixels. Later, in order to improve the image quality, soft matting[9] was added, but this algorithm was time-consuming; Meng*et al.* [10] used dark channel prior and boundary constraint mapping to carry out image defogging processing, Wang *et al.* [11] divided the image into sky region and non-sky region, the coefficients of these two region are estimated respectively，and then combined with the region to refine. Tarel *et al.*[12] is assumed that its own atmospheric dissipation function changes smoothly locally, in order to estimate the transmittance coefficient more accurately, median filter is used instead of the minimum filter in He's algorithm, in order to achieve the purpose of defogging, the defect of this defogging algorithm is easy to produce halo effect at the edge of depth of field mutation.

In recent years, the rapid development of deep learning has attracted extensive attention of researchers, and more and more researchers begin to study remove fog based on deep learning, Li *et al.*[13]Proposed a convolutional neural network defogging method which combined transmission with atmospheric light value. Cai*et al.*[14] use convolutional neural network (CNN) to learn the mapping relationship between fog image and transmittance, the haze characteristics are studied through multi-scale mappingand maximum pooling , in order to realize the defogging of a single fog image.

Deep learning has a great improvement in the timeliness of processing batch images, but the effect of natural images after defogging is not stable, which depends on the atmospheric scattering model. In terms of defogging based on physical models,the dark primary color prior has attracted the attention of researchers due to its simple theory and method, it is only suitable for non-sky region, the theory couldn't hold for sky region or some bright region.

Using dark channel prior to remove fog will result in large region halo and serious distortion in the sky region. After introducing the defogging process using dark channel prior,a method of removal fog based on sky region segmentation will be proposed,which can avoid the bad phenomena caused by the use of dark channel prior. After processing the image,thealgorithm of OTSU was used to identify the sky region and non-sky region,the image divided into two parts, one of part is the sky region, the other part is the non-sky region.Next, two unknown parameters in the atmospheric scattering model are obtained by using the improved algorithm, and finally the scene brightness is restored, This method can enhance the contrast of sky region and improve the image quality，it is of great significance to improve the recognition rate and work efficiency of machine vision system in fog environment.

2. Original algorithm of dark channel prior

The most widely used model in foggy environments [15]:

$$I(x) = J(x)t(x) + A(1-t(x)) \quad (1)$$

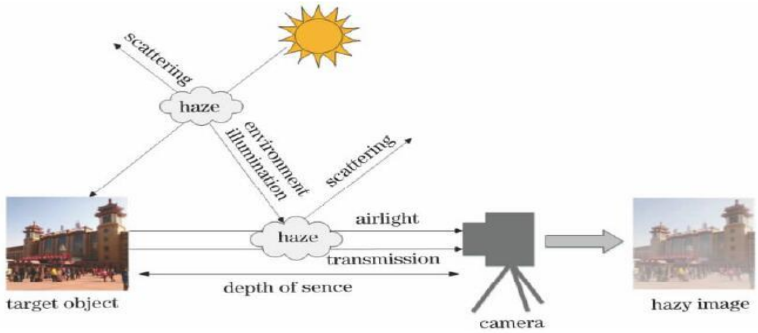


Figure 1: Physical model of atmospheric scattering

$I(x)$ represents the scene image observed in the fog environment; $J(x)$ represents the scene image in the fog free environment; $t(x)$ represents the sky transmittance; A represents the atmospheric light; $J(x)t(x)$ represents the remaining part of the reflected light attenuated by the atmospheric scattering.

Dark channel priori principle: in a given fog-free image, every local region may have shadows, or pure color and black things. In every local region, there is likely to be at least one color channel with a low value.

The dark primary color priori is based on most of the outdoor non-sky parts, and there will be a very low value in at least one color channel in the local region, which tends to 0:

$$J^{dark} \to 0 \quad (2)$$

To simplify Equation (1), both sides of this equation are divided by a non-zero number, and get:

$$\frac{I(x)}{A} = \frac{J(x)t(x)}{A} + (1 - t(x)) \quad (3)$$

In a local region, estimating the minimum value of dark primary color on both sides, and get:

$$\min_{y\in\Omega(x)}\left(\min_c \frac{I^C(x)}{A}\right) = t(x)\left(\min_c \frac{J^C(x)}{A}\right) + 1 - t(x) \quad (4)$$

According to Equation (2):

$$J^{dark}(x) = \min_{y\in\Omega(x)}\left(\min_c J^C(x)\right) = 0 \quad (5)$$

Considering the existence of atmospheric perspective phenomenon, if the fog is completely spilled, the removed image will look not natural, and the depth information may be lost. Therefore, a small amount of fog should be retained for distant objects, we introduce a constant parameter into the equation ξ, and this value is generally set as 0.95.According to Equation (4):

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

According to the values of ambient light and transmittance, the atmospheric scattering model is used to restore the scene brightness:

$$J(x) = \frac{I(x) - A}{\max\left(t(x), t_0\right)} + A \quad (7)$$

When the transmittance value is small, the noise of the obtained fog-free image is amplified. a minimum value of transmittance is given. when the value of t is less than t_0, the value of t_0 is generally set as 0.1.

Figure 2: The defogging result of dark channel prior

Dark channel prior could not applicable to the sky region and the bright region, the value range of transmittance is generally [0，1], if the value is not correct, it will result in an expansion of ten times or even dozens of times. In addition, the estimation of environmental value is not accurate, which will seriously affect the result,causing the image noise to be amplified, Figure 1 shows that the paper [8] using dark channel prior to remove fog, which results in a large region of halo and distortion in the sky region.

3. The improvement of defogging method

In equation (1),if a fog-free image is required, two parameters are calculated for ambient light and transmittance, the specific stepsof image defogging algorithm in this paper are shown in Figure 3:

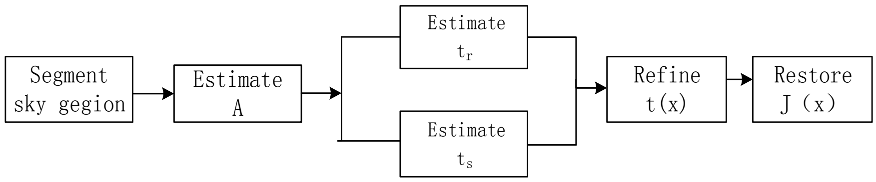


Figure 3: The specific process of the algorithm in this paper

3.1 Estimating the ambient light

Global atmospheric light is also called ambient light, the brightness of the image is affected by atmospheric light. A value is too small, the image after removal fog will have greater exposure. The overall brightness of the image is too high, resulting in colordistortion and color deviation, if the value of the ambient light is too large, the overall color of the image after fog removal is dark and less bright. In order to obtain better defogging effect, other operations must be done on the image to improve the image brightness, which increases the cost of defogging algorithm. In this paper, according to reference [8] to estimate the value of environmental light, it is to take the lightest pixel in 0.1% of the dark channel and to find the corresponding pixel point in the figure as the value of environmental light.

3.2 Sky segmentation

The above content, which introduces the dark channel prior defogging method and the result of defogging, dark channel prior could not apply to some sky or some bright region. The sky region is a very large, connected and high-intensity region, which provides a good foundation for the segmentation of the sky region,to make it easier for the algorithm to identify sky region and non-sky region.Firstly, the image with sky region is divided into two parts, one is sky region, the other is non-sky region, these steps involve image preprocessing technology，including the gray-scale processing of the image, considering that the image captured in the fog environment contains a lot of noise. Therefore, after converting the image to gradient image, foggy images are denoised by median filtering, gradient information is distinguished according to the set threshold, thealgorithm of OTSU was used to identify the sky region and non-sky region, the image is divided into sky region and non-sky region.The following image shows the preprocessing process and image segmentation effect.

Grayscale imageGradient imageSky segmentation

Figure 4: The image processing

3.3 Estimating the medium transmittance

When using the atmospheric scattering model to recover the scene, two unknown parameters are required, one is the value of ambient light and the other is the value of transmittance, after calculating the transmittance of the non-sky region, this paper proposes an adaptive method to calculate the transmittance of the sky region. this method has greatly improved the coordination of color proportions in the sky region of the image, and its authenticity and reliability have been further improved. The details and contrast of the image are enhanced after defogging.

Under the condition that the ambient light is known, according tothe equation 6, the transmittance of non-sky region can be calculated, the specific expression is as follow:

$$t_r(x) = 1 - \min_{y\in\Omega(x)}\left(\min_c \frac{I^C(x)}{A}\right) \quad (8)$$

In Figure 1,it is shown that after dark channel prior is used to remove fog, this method leads to image halo and distortion. we should focus on improving the quality of the sky region and enhancing the contrast of the image, therefore, the calculation of transmittance in the sky region should be more accurate and effective, noise amplification should be avoided as much as possible, halo and color distortion also should be avoided, after estimating the transmittance value of the non-sky region, in order to correct the transmittance of the sky region, the transmittance of the sky region should be appropriately increased,in this paper, an adaptive method is adopted to increase the transmittance of the sky region:

$$t_s(x) = (1 + \mathrm{n}/8)\cdot t_r \quad (9)$$

In the above equation, t_s represents the transmittance of the sky region, n represents the proportion of the whole image occupied by the sky region, $t_r(x)$ represents the transmittance of non-sky region.

Transmittance is obtained by combining the transmittance of sky region and non-sky region, filter is used to refine transmittance image. local details of the input image are optimized and smoothed by a bilateral filter[15],the filter is used to optimize transmittance $t(x)$, it is assumed that each pixel in the transmittance image is p, coordinate is (x, y), and gray value is T_p, q represents a point in the local region of a pixel, G_{σ_d} represents the spatial proximity factor, G_{σ_r} represents the gray similarity factor respectively,after bilateral filtering optimization, the final transmittance of the sky region is $t(x)$:

$$t(x) = \frac{1}{W}\sum_{q\in\Omega} G_{\sigma_d}\left(\|p-q\|\right) G_{\sigma_r}\left(T_p - T_q\right)\tilde{t}(x) \quad (10)$$

W is the normalization factor, and the value is:

$$W = \sum_{q\in\Omega} G_{\sigma_d}\left(\|p-q\|\right) G_{\sigma_r}\left(T_p - T_q\right) \quad (11)$$

The refined image is smoother than the original transmittance, and the ability to restore the image details and contrast are improved,as shown in Figure 5 below:

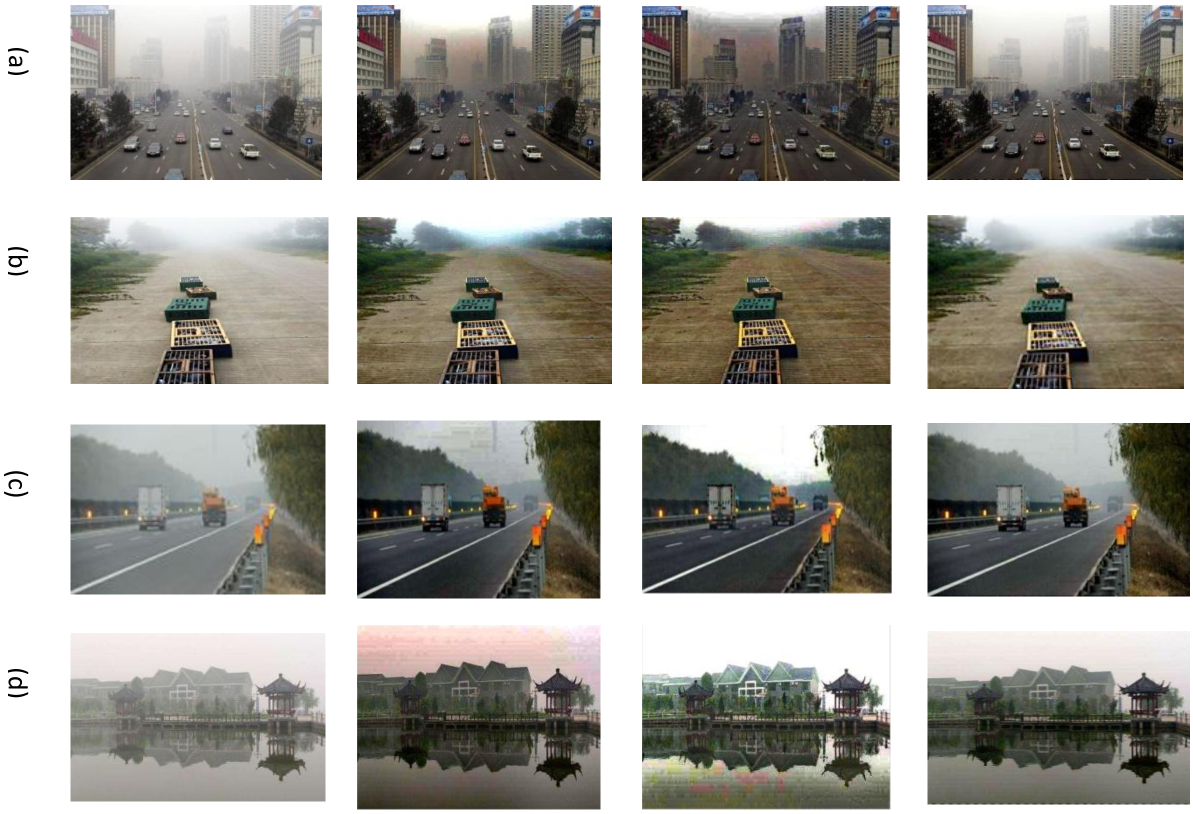
Figure 5: Comparison of transmittance before and after refinement

4. Experimental results

Based on the above theories and methods, after estimating atmospheric ambient light and transmittance values,using atmospheric scattering model to restore scene brightness, Figure 6 was simulated on the software Matlab2010b for fog removal.

Figure 6: Experimental resultof this paper

This experimental results show that the sky region segmentation method is adopted to remove fog, great improvement in image recognition rate,compared with image 1,the proposedmethod in this paper avoids the halo and distortion in the sky. The image color distribution proportion is coordinated and the brightness is moderate, which can meet the purpose of defogging.In this paper, five groups of fog images under different environments were added to verify the effect of the proposedalgorithm, it iscompared with the paper [8] and the paper [10], Figure7 shows the results of fog removal experiments with different algorithms.



(f)

Figure 7: Experimental results of defogging with different algorithms

The overall visual effect can be seen directly， in this paper [8],the method of dark channel prior is used, halo and color distortion will appear in the sky region,after the algorithm of thispaper[10] was used to remove fog, the sky regionwas overexposed， distortion occurs in most region， by using the proposed algorithm in this paper, the color distortion and halo phenomenon in the sky can be avoided and can be restored to nature. From the local region analysis,in group d,distinct effects appear at the top edge of the image defogging, the light blue region appears after the dark channel prior is used to remove fog, indicating that the color distortion occurs in this region.The algorithm ofthis paper 8, which performs better than the algorithm in this paper on the whole,even though the algorithm in this paper leaves fog to some extent,in group d, the shadow of the house inthe water is redafter using dark channel prior to remove fog,in this paper [10], it is more obvious of the red region in the defogging algorithm, but the red region could not appear after using the proposedalgorithm in this paper.Finally, from the perspective of overall and local comprehensive evaluation, compared with the previous two algorithms, the image after defogging has clear outline, rich details and moderate brightness, which can achieve the purpose of defogging.

In order to verify the experimental results and assessment the clarity of image after fog removal, the feasibility of this algorithm is objectively verified by calculating the information entropy (IE) and average gradient (AG), which are used as important quantitative criteria for image evaluation. The clearer the contour of the image and the richer the detail content are, the higher the entropy value and gradient value will be, in other words, the better the effect of the image after defogging will be, the higher the value will be. As shown in Table 1, the entropy and gradient values of the improved algorithm in this paper are increased compared with those of the previous algorithms, which proves the algorithm has improved effect.

Table 1 Comparison of information entropy and average gradient of image after defogging with different algorithms

image	Original image		Paper[7]		Paper [8]		Improved algorithm	
	IE	AG	IE	AG	IE	AG	IE	AG
(a)	7.833	3.638	7.457	4.375	7.487	4.385	7.772	5.236
(b)	7.539	3.758	7.434	3.332	7.518	4.250	7.733	4.662
(c)	7.185	3.022	7.460	3.453	5.938	3.887	7.485	5.465
(d)	7.122	2.326	7.649	2.365	7.818	2.360	7.543	3.856
(e)	7.479	2.522	7.462	2.563	7.809	2.865	7.260	3.650

5. Conclusion

1. Sky region is a very large, connected and high-intensity region, which provides a good foundation for sky region segmentation and makes it easier for the algorithm to identify sky region and non-sky region.
2. The image is divided into sky region and non-sky region, an adaptive method is proposed to calculate the transmittanceof sky region， it is helpful to deal with the problem of color distortion in sky area.
3. After merging the sky and non-sky areas, transmittance image needs to be processed by bilateral filtering, contrast of the image have been improved to some extent.

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