Single Image Defogging Algorithm based on Dark Channel Priority

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***Abstract*—Based on dark channel priority, the paper proposes an improved defogging algorithm of single image which can defog the foggy images rapidly. The algorithm in the paper applies the method combining adaptive median filter and bilateral filter to figure out clear dark channel on the edge. And the algorithm is based on the physical model of foggy images to estimate transmission. Compared with the traditional algorithm, the estimated transmission is detailed and clear, and has no need to be optimized, which not only overcomes the disadvantages of traditional algorithm using plenty of time to optimize transmission, but also reduces the complexity of the algorithm. The experimental results indicate that the algorithm realizes rapid and high-quality defogging on single image.**

***Index Terms*—Image Restoration, Defogging, Dark Channel Priority, Adaptive Median Filter, Bilateral Filter**

I. Introduction

Fog is a kind of common natural phenomena. In the misty weather, turbid media of atmosphere such as molecular and suspended particles can create pollution of feedback images and makes fidelity and contrast of the color for images reduce to a great extent. The images as a whole is vague, the details content can't be recognized and the color is biased toward gray and white, which lead to great reduction of dependability for outdoor vision system such as outdoor target recognition, automatic monitor and satellite remote sensing monitoring. Therefore, it has important significance in fog-degraded images clearness.

But fog-degraded images clearness is a challenging task, especially rapid defogging on single image. Because depth information dependent by fog in atmosphere is unknown and acquisition for the depth of single two-dimension image is an unconstrained problem. If multiple images are used to defog, different types of imaging device are needed to shoot multiple images in the same location [2, 3], which not only has low economic cost, but also is difficult in application for dynamic scene. Or multiple images of the same scene in different weather conditions are collected [4, 5], which is infeasible for outdoor vision system with high real-time demand. Therefore, it is necessary to make rapid defog on single image, which can improve the reliability of all kinds of outdoor vision system in foggy weather.

In recent years, defogging technology for single image has achieved significant progress which is mainly from the following two aspects, one is enhancement algorithm based on image processing, and the other is recovery algorithm based on physical model. As for the former, the typical algorithm is Retinex algorithm which is a kind of model describing color invariant and has a good effect of reinforcing on color image with long-scale contrast formed because of ununiform lighting. Although the image enhanced by Retinex algorithm is on the basis of applying msrcr algorithm with color restoration [6], it is easy for the algorithm to cause color inconsistency or details lost. Because the algorithm needs the user to set multiple gaussian filter scale parameters and the size of parameters and low-frequency color domain of image after enhancement have close relationship with high-frequency details. Recovery algorithm is the the defogging algorithm for single image based on dark channel priority [1] and has better effect. The algorithm can make local repair on the image color in zones according to mist concentration and has good defogging result, and the recovered image color approximates reality and has high definition.

In this paper, an improved haze removal algorithm from a single image is proposed, based on dark channel prior. It can remove haze very fast from the haze image. The dark channel, which is very fine, is calculated with a kind of adaptive median filter and the bilateral filter. The transmission can be estimated, based on the method, from the physical model of imaging in haze. And it is also fine

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compared with the transmission estimated by the original algorithm, so that it could be without optimization, and a lot of time is saved, which is spent on refining the transmission by the original algorithm. The complexity of the algorithm is reduced significantly. The experimental results show that the haze image is dehazed very fast with a good quality by the algorithm.

II. PROPOSED SCHEME

A. Defogging Algorithm based on Dark Channel Priority

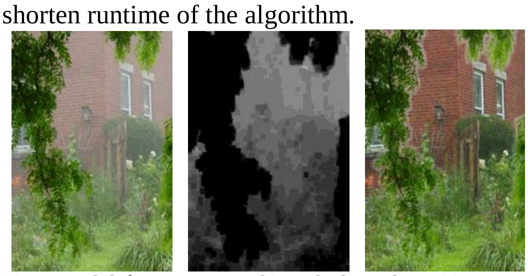
Dark channel priority is the regularity obtained from the statistics on massive outdoor image without fog. As for most local area except for the sky , there are at least one color channel whose pixel brightness valueapproaches zero in three color channels of GRB. There are three major reasons, the shadow of architectures, people and vehicles, the projection of natural scenes such as trees and rocks, bright-colored objects such as red or yellow flower and leaf, green plant and blue water, and the pixel brightness value of some channels is very low in 3 channels of RGB which also has dark-color surface or objects such as the ground surface and stones. Above all, the scene without fog is full of color, dead colour or shadow, and has dark channels for image. However, brightness valueof dark pixels for images disturbed by fog can be polluted by white light to become higher, that is, the higher the brightness value in ark channels except for the sky, the higher the density of fog in the position. So the dark pixels which are polluted by the fog can be used to estimate concentration of fog and transmission information of light.

With the algorithm in literature [1] which is called H, dark channels can be described :

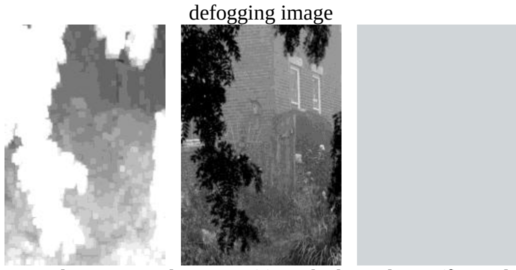
$$J_{dark}(x) = \min_{c\in\{r,g,b\}}(\min_{y\in\Omega(x)}(J_c(y))) \tag{1}$$

(1) represents a RGB image without fog, Jc represents a channel in RGB channel of J and Jc is a gray image without fog. $\Omega(x)$ is a piece of square area with x as center and the length of a side takes odd. $\min_{y\in\Omega(x)}(J_c(y))$ is 3 rough gray images with checkerboard effect by taking $\Omega(x)$ as filter to make nonlinear minimum filtering on Jc of three channels. Each pixel of Jdark is the minimum which is taken from three pixels of the corresponding position for 3 gray images. So according to dark channel priority, the intensity of Jdark is always very low and approaches zero as for the area which is not the sky.

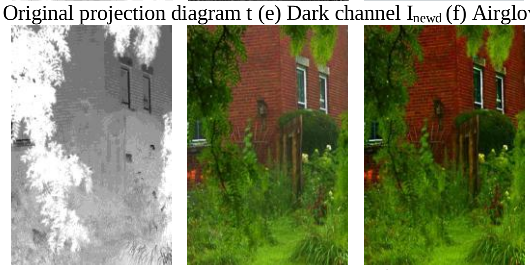
I is used to show an atomizing RGB image, dark channels of I obtained according to Formula 1 is Idark to which has rough gray image with checkerboard effect (see Figure 1b), serious halo trace appears at the edge of image after defogging(see Figure 1c). The reason is that transmission picture t is also rough (see Figure 1d). Because HE algorithm uses nonlinear minimum filtering in formula 1 in the process of calculating t, which results in checkerboard effect of t, HE algorithm applies image repair method to optimize the rough transmission diagram t. Although clear image can return after applying optimized transmission diagram t, the calculation of transmission diagram t is the biggest bottleneck for the algorithm. Side length value of Matting Laplacian giant matrix to be generated in the optimizing process is the area value of defogging images, and each element of Matting Laplacian matrix can be obtained by multiple cycle operation. By testing the image of 800×600 pixel, the whole calculation process takes about 103s, in which optimizing transmission diagram accounts for 94s. The above results are acquired from common PC which has the operating system with Windows XP, CPU with AMD quad core 3.0GHz and memory with 4G RAM. And using 2G RAM can result in memory overflowing, which makes optimization unable to be completed. The algorithm of optimizing transmission diagram is too complicated, which is the biggest obstacle to limit practicability of HE algorithm. However, the paper improves the algorithm which is improved in the paper reduces complexity of calculation significantly in the condition of not influencing the defogging effect, which can shorten runtime of the algorithm.



(a) Original defogging image (b) Dark channel I_{dark} (c) Original defogging image



(d) Original projection diagram t (e) Dark channel I_{newd} (f) Airglow A



(g) Projection diagram t (h) New algorithm defogging diagram (i) Complete defogging diagram

Figure 1. (a-i)

B. Improvement on the Method of Calculating Dark Channels

Firstly, physical model is established for is atomizing image according to the physical property of light transmitting in fog. The following is the description of optical model of atomizing image [12]; the model is commonly used for researching the defogging technology [1, 7, 8].

$$I(x)=J(x)t+A(1-t) \quad (2)$$

I is RGB image collected in the foggy weather by outdoor visual system and is known. J is RGB image of scenes in the weather without fog, that is, the nearer the atomizing image with J after recovering, the better. t is used to describe the part which has not been scattered in the process of light transmitting visual system for light, that is, the description of the degree of image information in each area is called transmission diagram. A is atmospheric optical components, the brightness of the sky in the weather without fog. Brightness value of each channel for A should be calculated respectively for precision. Obviously, t=1, I(x)=J(x) in the weather without fog, and I is used to estimate t and A to acquire J in the foggy weather.

According to HE algorithm, estimating t and A needs to know Idark, but Idark obtained by HE algorithm is rough, which lead to the roughness of t and spending much time optimizing t, so that the time of calculating defogging is prolonged, and the practicability of the algorithm is limited. The paper proposes a kind of improvement algorithm to calculate dark channels, and the new dark channel is called Inewd and is refined. So t obtained with the improved algorithm is also refined without need to optimize, which shortens the time of the whole process of defogging.

Dark channels of atomization image are estimation for the density of fog. HE algorithm applies the minimum value filtering, which leads to the estimation roughening. But adaptive median filtering in the paper is different from the minimum value filtering, the former approximates to smoothing filtering, and this kind of filtering can retain boundary part in which brightness value of image can change rapidly. The destination is as follows:

kind of
LA: If Zmin<Zmed< Zmax,it turns to LB
or mask size would be increased
If the size is not more than Smax, LA will be repeated.
or Zmed will be output
LB: If Zmin<Zxy< Zmax, Zxy will be output
or Zmed will be output

Mask size is odd and starts from 3. Smax is the biggest mask size. Zxy is the brightness value of coordinate(x,y). Zmin, Zmed and Zmax is respectively the minimum, mid-value and the maximum with (x,y) as center. Next, dark channel Inewd will be calculated, concrete procedures are as follows:

Firstly, the minimum M of each pixel of I in RGB channel is calculated, and M is a gray image:

$$M(x)=\min_{c\in\{r,g,b\}}(I_c(x)) \quad (3)$$

Next, M uses adaptive median filtering (Smax adaptation takes 1% of the size of atomization image), which can make the value of pixels of dark channels more reasonable at the local range, for example, a brighter local min emerging in the area of uniform brightness can lead to minimal local high light value appearing in M. But using filtering for M can remove hight light value to some extent, and has better edge compared with traditional median filtering.

$$M1=adpmedfilt2(M) \quad (4)$$

M1 can be as local average of M, and details high-frequency part of M is blurred inevitably. The fuzzy of details generated by median filtering is more slight than the fuzzy of details generated by the minimum value filtering [9]. However, the slight fuzzy also needs to be processed, or detail section for atomization image will be fuzzier after defogging. Bilateral filtering just can dispose the details fuzzy generated with median filtering, which makes the image after defogging is more natural. Bilateral filtering is defined as :

$$BF[I]_p=\frac{1}{W_p}\sum_{q\in S}G_{\sigma_d}(\|p-q\|)G_{\sigma_r}(|I_p-I_q|)I_q \quad (5)$$

The above is formula 5. Ip and Iq are the brightness value of pixels, p and q. Wp is as follows:

$$W_p=\sum_{q\in S}G_{\sigma_d}(\|p-q\|)G_{\sigma_r}(|I_p-I_q|) \quad (6)$$

Formula 6 is normalization coefficient. G_{σ_d} and G_{σ_r} is respectively gaussian kernel with σ_d and σ_r as standard deviation on static airspace D and dynamic range R. || represents euclidean distance. So bilateral filtering not only considers spatial relationship of pixels, but also takes similarity relation of brightness value for pixels into consideration. It can smooth images and make images clear [10]. The operation on M1 is as follows:

$$M2=BF(M1,S,\sigma_d,\sigma_r) \quad (7)$$

In order to achieve the effect of clearness, S is two times size of adaptive median filter mask, σ_d takes 10 and σ_r takes0.1. BF uses rapid bilateral filtering -in the literatures [14, 15] for improving the operation speed. It firstly calculates one of the biggest dynamic value on the basis of M1 and S, and filters respectively based on size of σ_r , which makes complexity be O(n)

Finally, Inewd should satisfy the constraint condition, 0≤Inewd≤M:

$$Inewd=max(min(M2,M),0) \quad (8)$$

Dark channel Inewd obtained with the improved algorithm is mist concentration diagram (See Figure 1e). Compared with Idark, the estimating results of the improved algorithm is more meticulous and looks clearer. The pixel whose brightness value is zero in Inewd means the zone without the need to defog. Formula 4, 7 and 8 are merged into function newd for convenient explanation in the next chapter.

C. Estimation of Projection Diagram T and Airglow A

Each pixel of I and J in formula 2 is taken the minimum value in channel RGB

$$\min_{c\in\{r,g,b\}}I_c(x)=t\min_{c\in\{r,g,b\}}J_c(x)+A_c(1-t) \quad (9)$$

The operation on formula 4, 7 and 8 on both sides of formula 9 can obtain:

$$newd(\min_{c\in\{r,g,b\}} I_c(x))=newd(\min_{c\in\{r,g,b\}} J_c(x))t+A_c(1-t) \quad (10)$$

$newd(\min_{c\in\{r,g,b\}} J_c(x))$ =Jnewd, according to dark channel priority Jnewd=0, $newd(\min_{c\in\{r,g,b\}} J_c(x))=0$, and formular 11 is obtained:

$$t=1-newd(\min_{c\in\{r,g,b\}} \frac{I_c(x)}{A_c}) \quad (11)$$

According to the analysis above, dark channel priority doesn't apply to the sky, but the color of the sky in atomization images is very close to airglow A_c , so $I_c(x)=A_c$, t=0 in the sky. And because the light in the sky is from infinity and transmissivity t is close to zero, formula 11 applies to the sky area and non-sky area, and there is no need to process the sky area individually.

Estimating projection diagram t must estimate airglow A firstly on the basis of formula 11. In the literature [7], pixel value with high-light brightness in image I is regarded as airglow. And most defogging method for single image uses the method to estimate A. However, the brightest pixel in real image may be not in the sky but in a whited object. And s new method of estimating A must be adopted. As mentioned, dark channels of atomization images can obtain rough value of mist density (See Figure 1e). So reliability of estimating airglow can be improved by dark channels. Firstly, the pixel of 0.1% with the biggest brightness value in dark channels can be taken. And the corresponding positions of these pixels in I can be found, then the pixels responding to the positions can be found in three channels of I respectively. Finally, the biggest value of those pixels is taken from 3 channels of I to be as the brightness value of all pixels for the channels responding to A. And A can be estimated (See Figure 1f), and we should notice that A is not the brightest point in image I. The method estimating airglow A based on dark channels is more reliable than the method in literature [7].

Transmission diagram can be estimated through formula 11. But in reality, the air contains some impurity inevitably in the condition without fog. Therefore, the fog still exists for remote objects. It is the existence of fog that people feels the existence of depth, which is called areal perspective [11]. If the fog is removed completely, images look not true and the depth disappear (See Figure 1i). Therefore, a constant ω (0<ω≤ 1) can be set in formula 11 and the fog covered on the remote objects is reserved, and the modification makes defogging diagram more perfect. The value of ω is set according to concrete conditions. In the paper, ω selects a constant value, 0.85.

$I_c(x) / A_c$ =N, $newd(\min_{c\in\{r,g,b\}} \frac{I_c(x)}{A_c})$ is using the improved algorithm to acquire dark channel of N and is set as N_{newd} , transmission diagram t (See Figure 1g) is

$$t=1-0.85N_{newd} \quad (12)$$

D. Acquisition of Images after Defogging

According to A and t estimated in 2.2 and the formula 2, we can obtain:

$$J(x)=\frac{I(x)-A}{t}+A \quad (13)$$

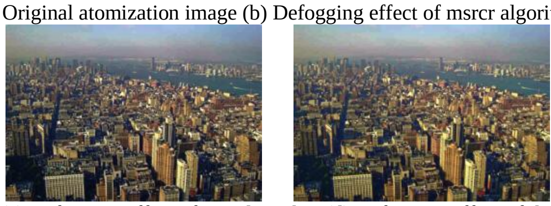
Transmissivity can't be zero, so t is set as a lower limit t0. The paper takes t0=0.1, and the final defogging image j (See Figure 1h) is:

$$J(x)=\frac{I(x)-A}{max(t,0.1)}+A \quad (14)$$

III. SIMULATION ANALYSIS

In order to verify the practicability and effectiveness of the improved algorithm, Matlab 2012a is used to make simulation experiment on common pc which has the operating system with Windows XP, CPU with AMD quad core 3.0GHz and memory with 4G RAM. The images of cities, outskirts and remote sensing which are polluted by fog are defogged. HE algorithm based on msrcr of retinex is applied. Visual effect, operation speed and objective image resolution are compared. The simulation results are shown in Figure 2, Figure 3 and Figure 4.

(a) Original atomization image (b) Defogging effect of msrcr algorithm



(c) Defogging effect of HE algorithm (d) Defogging effect of the improved algorithm

Figure 2. (a-b) Comparison of simulation effect for city images

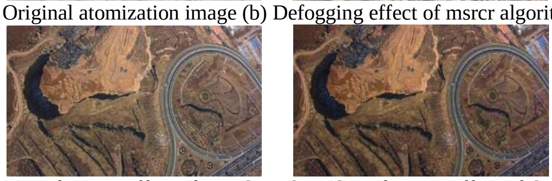
(a) Original atomization image (b) Defogging effect of msrcr algorithm

(c) Defogging effect of HE algorithm (d) Defogging effect of the improved algorithm

Figure 3. (a-b) Comparison of simulation effect for outskirts image

Three algorithms realizes the defogging to some extent. As mentioned, the color for defogging images with msrcr algorithm are somewhat distorted, for example, the color in the sky of Figure 2b bias dark and the transition is not natural, and the color of leaf in Figure 3b and the color of ground surface in Figure 4b. He algorithm and the improved algorithm all achieve better effect of defogging. For example, the color of the sky in Figure 2d is natural and the level is clear, the defogging effect of the woods in Figure 3d is good, and the texture of ground surface in Figure 4d is more clear. Most of all, the new transmission diagram t is very clear. There is no halo formation left after defogging on the leaf in Figure 3a (See Figure 3d), and the detail texture of leaf in left side of Figure 3d is more clear because of the application of bilateral filtering.

(a) Original atomization image (b) Defogging effect of msrcr algorithm



(c) Defogging effect of HE algorithm (d) Defogging effect of the improved algorithm

Figure 4. (a-b) Comparison of effect for remote sensing images

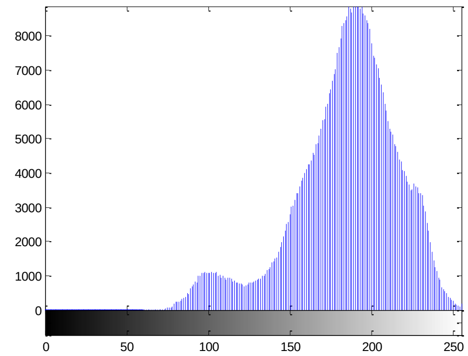
Next, various algorithms are compared objectively. And histogram, mean value, standard deviation and entropy of R channel from image 4(a) to (d) are calculated, and the results are shown in Figure 5 and Table 1.

TABLE I. MEAN VALUE AND STANDARD DEVIATION OF R CHANNEL FROM IMAGE 4(A) TO (D)

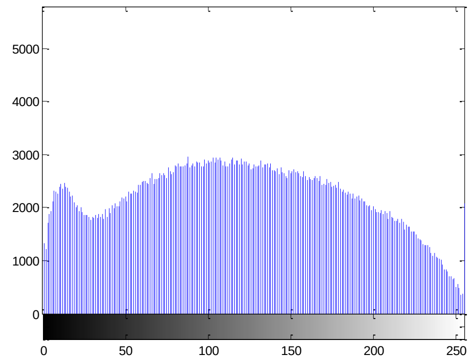
	Mean value	Standard deviation
Figure 4(a)	183.5311	32.9575
Figure 4(b)	118.5674	65.2248
Figure 4(c)	116.6221	42.7048
Figure 4(d)	109.1401	45.7910

From Figure 5, we can see that the pixel stretch of histogram for the algorithm in the paper is greater and has evident spike, which indicates that the image is clear and there is high contrast. And we can see from Table 1 that the mean value of algorithm in the paper is the minimum, which shows that the interference of fog is the minimal. But it has an appropriate standard deviation, which indicates that the image includes the most information and is the clearest.

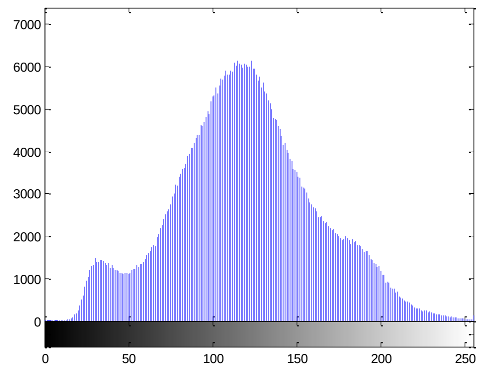
Then statistical evaluation method of image quality which is proposed in literature [22] was applied. And the statistical results show that when gray average is between 100 and 200, and the standard deviation is between 35 and 80, the quality of the images is better, as shown in Figure 6. And concrete steps of statistics are: the image is decomposed into different subblocks (50×50), and the standard deviation σ of each subblock is figured out and is for averaging, and multiplying the average standard deviation σ and gray average of image can get evaluation result. The greater the multiplying result is, the better the quality of image is. The statistical results of image are shown in Table 2.



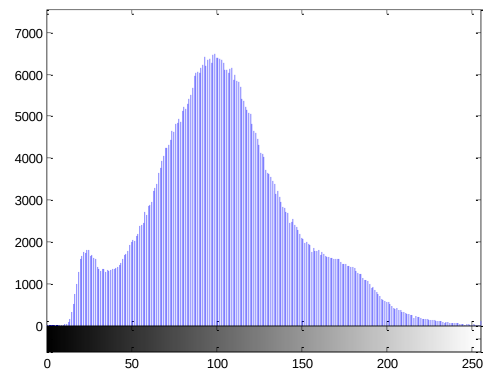
(a)



(b)



(c)



(d)

Figure 5. (a-d)Histogram of R channel from figure4(a) to (d)

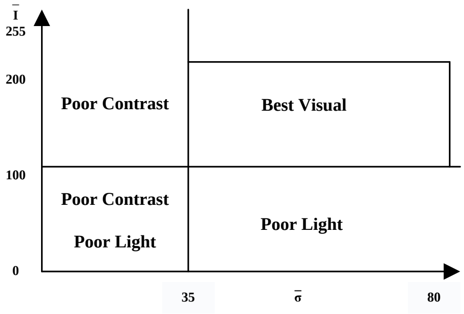


Figure 6. Distribution of visual effects

TABLE II. STATISTICS OF $\bar{I}\times\bar{\sigma}$ (SUB-BLOCK SIZE 50×50)

	Original	Msrcr	He	This paper
Fig2(a-d)	622. 661 2	2.9e+03	3.8e+03	3.9e+03
Fig3(a-d)	764.5943	2.4e+03	2.9e+03	3.3e+04
Fig4(a-d)	876.1571	2.5e+03	3.3e+03	3.5e+03

We can see from Table 2 that quality evaluation result of the images which were processed by the algorithm in the paper was better than that of the traditional algorithm. $\bar{I}\times\bar{\sigma}$ value of the original image is less, and the corresponding brightness and contrast are worse. Quality evaluation data which were processed by the algorithm in the paper are improved generally compared with traditional algorithm, which indicates that the processing result of the algorithm in the paper were better than that of traditional algorithm.

Lastly, the operation time of the algorithm and objective image resolution area analyzed and the images are evaluated by using entropy function and Tenengrad function [13]. The results are shown in Table 3, Figure2, Figure 3 and Figure 4 are form top to bottom.

TABLE III. SIMULATION DATA

	Original	msrcr	HE	Paper
entropy	7.5256	7.4830	7.6742	7.6844
Bre	4.3e+03	8.8e+03	9.6e+03	1.1e+04
Ten	1.2e+05	2.5e+05	2.7e+05	2.9e+05
Time		8.3156	134.3984	12.9643
entropy	6.9834	7.0565	7.1657	7.1455
Bre	2.2e+03	3.5e+03	2.7e+03	2.8e+03
Ten	5.6e+04	8.1e+04	6.9e+04	7.0e+04
Time		9.2847	129.3746	10.9874
entropy	6.9439	7.9056	7.3155	7.3103
Bre	2.2e+03	8.9e+03	6.1e+03	6.8e+03
Ten	5.7e+04	2.2e+05	1.5e+05	1.6e+05
Time		8.5769	117.9324	9.7193

From simulation images and Table 3, we can see that the defogging effect of HE algorithm and the algorithm of the paper is consistent basically, but the algorithm of the latter is 10% of HE algorithm, which indicates that the improved algorithm has certain practicability and effectiveness. Although the results of msrcr in Table 1 are good, the algorithm is not the restoration algorithm based on physical model, and the algorithm evaluated functions without color fidelity as the premise, which causes virtual height of the results.

IV. CONCLUSIONS

The paper proposed a defogging algorithm for single image based on dark channel priority which can make rapid defogging on foggy images. For the disadvantage of HE algorithm, that is, much time is used to optimize transmission diagram, the paper applies a method combining adaptive median filtering and bilateral filtering to calculate dark channels, The dark channels are refined, and transmission diagram t estimated by the method is also refined without need to optimize, which reduces the complexity of algorithm significantly and overcomes the bottleneck of low speed for HE algorithm. The algorithm realizes rapid and high-quality defogging on single images in the condition of not influencing defogging effect. The improved algorithm has flexibility, practicability and effectiveness, and makes the reliability of outdoor visual system in foggy weather improve dramatically, so it has widely practical value.

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