2012 IEEE International Conference on Information Science and Technology
Wuhan, Hubei, China; March 23-25, 2012

# Fast Image Dehazing Using Improved Dark Channel Prior

Haoran Xu, Jianming Guo, Qing Liu, and Lingli Ye

*Abstract* — **In the frog and haze climatic condition, the captured picture will become blurred and the color is partial gray and white, due to the effect of atmospheric scattering. This situation brings a great deal of inconvenience to the video surveillance system, so the study of defogging algorithm in this weather is of great importance. This paper deeply analyzes the physical process of imaging in foggy weather. After full study on the haze removal algorithm of single image over the last decade, we propo se a fast haze removal algorithm which based on a fast bilateral filtering combined with dark colors prior.This algorithm starts with the atmospheric scattering model, derives a estimated transmission map by using dark channel prior, and then combines with grayscale to extract refined transmission map by using the fast bilateral filter. This algorithm has a fast execution speed and greatly improves the original algorithm which is morre time-consuming. On this basis, we analyzed the reasons why the image is dim after the haze removal using dark channel prior, and proposed the improved transmission map formula. Experimental- results show that this algorithm is feasible which effectively restores the contrast and color of the scene, significantly improves the visual effects of the image. Those image with large area of sky usually prone to distortion when using the dark channel pr ior,Therefore we propose a method of weakening the sky region, aims to improve the adaptability of the algorithm.**

## I. Introduction

In the fog and haze weather condition, the image quality of outdoor screen are usually degraded by the Scattering of large number of suspended particles(e.g., fog, haze, smoke, impurities) suspended in the atmosphere. This phenomenon directly affects the normal work of automatic monitoring system, intelligent transportation systems and outdoor recognition system. Therefore, the effective haze removal of image has a major significance to improve the stability and roubustness of the visual system. Haze removal is a challenging problem because fog depends on the unknown scene depth information. The current haze removal method can be divided into two categories: image enhancement and image restoration. Image enhancement excludes the reasons of fog degrading the image quality. This method is applicable to a broader scope; it can improve the contrast of haze image, But it is likely to cause the loss of image information. Image restoration firstly studies the physical process of image imaging in foggy weather. Then, the degradation model of fog image will be established.

At last, after the degradation process inverted, the fog-free image without the interference of degradation will be found; thereby the quality of haze image could be improved. This approach is high targeted and could get the clear and natural image of haze removal, usually does not cause loss of information, therefore image restoration has become a research focus for over a decade. Typical methods of image restoration to the fog have the following. Narasimhan have studied on the methods of extract scene depth information from many different angles. For example, the use of binary scattering model to extract scene depth information from the color image in different weather conditions [1][2]; Depnding on the different polarization properties of scattered light, they use polarized light in different directions to restore the scene depth information [3]-[5]; Calculated by determining the depth of the boundary is not continuous, under different weather conditions from the pieces of gray-scale image of the scene to extract depth information [6]. But there are some limitations in the above ways to extract the depth of the scene. Such as the method using light polarization is only applicable to weaken mist but not strong fog. While some other methods require the same scene under different world image or user interaction, so it is difficult to meet real-time defo gging for dynamic scenes.Tan et al. [7] found that haze-free image have higher contrast than haze image through statistical, thus they using the way of maximizing local image contrast to achieve haze removal, but this method do not consider the process of light component often leads to over-restored image color saturation and distortion. Fatal et al [8] assume that the propagation of light projected and the projection of target surface is partially uncorrelated, then they estimate the reflectivity of the scene, and derive the transmission rate of light propagating in the air. Since the method is based on mathematical statistics, it needs enough image of color information. However, the image is missing a lot of color information in the haven fog condition, this algorithm can not got trusted transmittance map, resulting a distortion of recovered image.

In the CVPR 2009 Conference, Kaiming He et al [9] proposed a new algorithm, the dark color priori, to haze removal. By collecting a large number of clear fog-free images, they found that low-intensity pixels always exist in the most of the local image area except sky. According to this law, we can directly calculate the light transmittance map, combining with fog imaging model and the image of soft matting technique to repair the various parts of the color; we can effectively achieve good results to the fog.

This paper proposed improved method for the flaws of dark channel prior. We improve the algorithm by replacing the time-consuming soft matting part with fast bilateral filter to

Haoran Xu is with the school of Automation, Wuhan University of technology,Wuhan 430070, Hubei, China. He is a Master( e-mail:haoransun123 @163. com).

Jianming Guo is with the school of Automation, Wuhan University of technology, Wuhan 430070, Hubei, China. He is a professor(e-mail:jmguo63 @163.com).

Qing Liu is with the school of Automation, Wuhan University of technology, Wuhan 430070, Hubei, China. She is a Ph.D(e-mail:qliu2000@163. com).

Lingli Ye is with the school of Automation, Wuhan University of technology, Wuhan 430070, Hubei, China. She is a Master(e-mail: lingliyeiris @ 163.com).

get higher efficiency. Moreover we analysis the reason why traditional algorithm leads to dim image after haze removal and propose our improved transmission rate formula in order to get better visual effects of the image after dehazing. On this basis, taking into account that the Dark Channel Prior rule is not suitable for sky area, we decide to process this region with weaker method to improve the adaptability of the algorithm.

## II. DARK CHANNEL PRIOR

### A. Atmospheric Scattering Model

In computer vision and computer graphics, the atmospheric scattering model widely used to describe the formation of a haze image is as follow [2][7]:

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

Where $x$ is the location of the pixel, $I$ is the observed intensity $J$ 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 goal of haze removal to recover $J$, $A$ and $t$ from $I$. In formula (1), $J(x)t(x)$ is called direct attenuation, and $A(1-t(x))$ is called airlight.

### B. Dark Channel Prior

The dark channel prior is based on the following observation on haze-free outdoor images: in most of the non-sky patc he s, at least one color channel has very low intensity at some pixels. In other words, the minimum intensity in such a patch should have a very low value. Formally, for an image J, we define [9]:

$$J^{dark}(x) = \min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} (J^c(y)) \right) \qquad (2)$$

where $J^c$ is a color channel of $J$ and $\Omega(x)$ is a local patch centered at $x$. Observation says that except for the sky region, the intensity of $J^{dark}$ is low and tends to be zero, if $J$ is a haze- free outdoor image. We call $J^{dark}$ the dark channel of $J$, and we call the above statistical observation or knowledge the dark channel prior.

### C. Haze Removal Using Dark Channel Prior

We first assume that the atmospheric light $A$ is given and transmission in a local patch is constant. Taking the min operation in the local patch and making both sides of the haze imaging equation (1) divided by the same $A$, we have:

$$\min_{y \in \Omega(x)} \left(\frac{I^c(y)}{A^c}\right) = \tilde{t}(x) \min_{y \in \Omega(x)} \left(\frac{J^c(x)}{A^c}\right) + (1 - \tilde{t}(x)) \qquad (3)$$

Taking the min operation among three color channels on the above equation, we obtain:

$$\min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} \left(\frac{I^c(y)}{A^c}\right) \right) = \tilde{t}(x) \min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} \left(\frac{J^c(x)}{A^c}\right) \right) + (1 - \tilde{t}(x)) \qquad (4)$$

According to the dark channel prior, the dark channel $J^{dark}$ of the haze-free radiance $J$ should tend to be zero:

$$J^{dark}(x) = \min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} (J^c(y)) \right) = 0 \qquad (5)$$

As $A^c$ is always positive, this leads to:

$$\min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} \left(\frac{J^c(x)}{A^c}\right) \right) = 0 \qquad (6)$$

Putting (6) into (4), we can estimate the coarse transmitssion $\tilde{t}$ simply by:

$$\tilde{t}(x) = 1 - \min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} \left(\frac{I^c(y)}{A^c}\right) \right) \qquad (7)$$

We introduce a constant parameter $\omega$ $(0 < \omega < 1)$ into Equation (7) that can keep a very small amount of haze for the distant objects:

$$\tilde{t}(x) = 1 - \omega \min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} \left(\frac{I^c(y)}{A^c}\right) \right) \qquad (8)$$

As the way used here for the minimum is traversing the region, the edge information of the obtained transmission map will be seriously lost. Therefore, in order to improve the accuracy, we need to refine transmission map using a soft matting method. Denote the refined transmission map by $t$. According to the algorithm of soft matting, the optimal $t$ can be obtained by solving the following sparse linear system

$$(L + \lambda U)\tilde{t} = \lambda t \qquad (9)$$

Where $L$ is the Matting Laplacian matrix, and $\lambda$ is a regulariz- etion parameter, $U$ is an identity matrix of the same size as $L$.

With the transmission map, we can recover the scene radiance according to the Equation(1). But the direct attenuation term $J(x)t(x)$ can be very close to zero when the transmission $t(x)$ is close to zero. The directly recovered scene radiance is prone to noise. Therefore, we restrict the transmission $t(x)$ to a lower bound $t_0$, which means that a small certain amount of haze is preserved in very dense haze regions. The final scene radiance $J(x)$ is recovered by:

$$J(x) = \frac{I(x) - A}{\max(t(x), t_0)} + A \qquad (10)$$

A typical value of $t_0$ is 0.1. The way of estimating the atmospheric light is that: we pick the top 0.1% brightest pixels in the dark channel. Among these pixels, the pixels with highest intensity in the input image are selected as the atmosphericlight. Note that these pixels may not be brightest in the whole image. For most outdoor images which don't include sky, the algorithm can perform very well in terms of haze removal. Our experimental results are shown in Fig.1.

## III. IMPROVED DARK CHANNEL PRIOR

### A. Bilateral Filtering Instead of Soft Matting

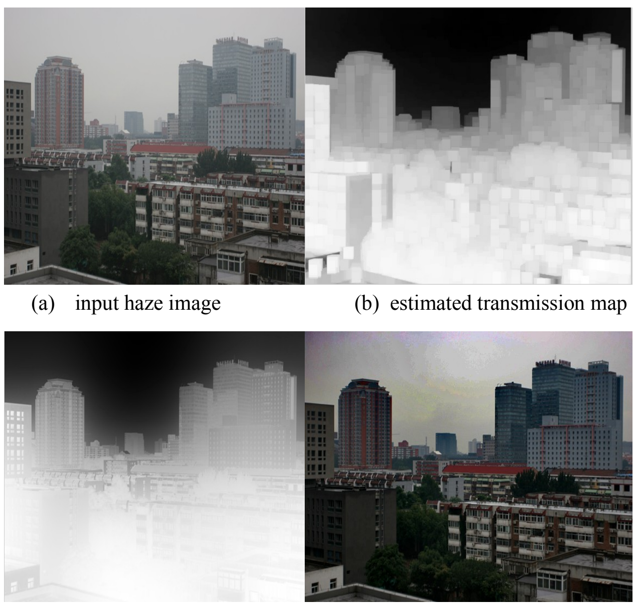
C.Tomasi and R. Manduchi [10] proposed a simple noniterative strategy to maintain the filter called the bilateral filer for the edge. The filter replaces each pixel by a weighted average of its neighbors. The weight assigned to each neighbor pixel decreases with both the distance in the image pla ne (the spatial domain $S$) and the distance on the intensity axis (the range domain $R$). Using a Gaussian $G_\sigma$ as a decreasing function, and considering a grey-level image $I$, the result $I^b$ of the bilateral filter is defined by:

$$I_p^b = \frac{1}{W_p^b} \sum_{q \in S} G_{\sigma_s}(\| p-q \|) G_{\sigma_r}(| I_p - I_q |) I_q \quad (11)$$

with

$$W_p^b = \sum_{q \in S} G_{\sigma_s}(\| p-q \|) G_{\sigma_r}(| I_p - I_q |) \quad (12)$$

where $\sigma_s$ control the size range of spatial filter, $\sigma_r$ control the value of rights according the different gray pixels near the p-oint, $W_p^b$ is standard measure which makes the weight normalizeation.



(a) input haze image (b) estimated transmission map

(c) refined transmission map (d) final haze-free image

Fig.1. Traditional dark channel prior defog effect

After analyzing the traditional dark channel priori algorithm, we find that: the soft matting step takes about 90% or more in the entire algorithm. So it is very important to find a way that can achieve a treatment effect as soft matting and also run faster. Bilateral filter just can achieve such results. So we use bilateral l filter instead of soft matting defogging. The flow is as follows:

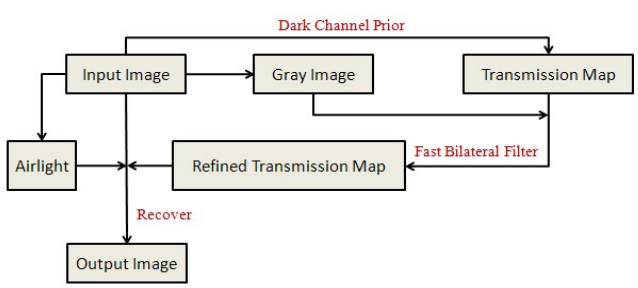



Fig. 2. Flow of improved dark channel prior

As the transmission map lose a lot of edge information and edge information is contained in the gray image, we ope-e rate the estimated transmission map with bilateral filter. The formula is as follows:

$$T_p^b = \frac{1}{W_p^b} \sum_{q \in S} G_{\sigma_s}(\| p-q \|) G_{\sigma_r}(| J_p - J_q |) \tilde{T}_q \quad (13)$$

with

$$W_p^b = \sum_{q \in S} G_{\sigma_s}(\| p-q \|) G_{\sigma_r}(| J_p - J_q |) \quad (14)$$

where $\tilde{T}$ is the estimated transmission map, $T$ is the refined transmission map, $J$ is the gray image of the input, $p$ and $q$ are two points in the image, and $G_\sigma$ is 1D Gaussian.

Although the bilateral filter has proved to be very useful, it is slow. It's nonlinear and its evaluation is computationally expensive since traditional accelerations. So we use a n-ew fast algorithm [11] to accelerate the algorithm. The key to this algorithm is to express the filter in a high-dimensional space where the signal intensity is added to the original domain dimensions.

### *B. Adjust Brightness to Defogging Image*

According to dark channel prior, the formulation of estimated transmission is as follow:

$$\tilde{t}(x) = 1 - \min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} \left( \frac{I^c(y)}{A^c} \right) \right) \quad (15)$$

But the exacting formulation is that:

$$\tilde{t}(x) = 1 - \min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} \left( \frac{I^c(y) - J^c(y)\tilde{t}(x)}{A^c} \right) \right) \quad (16)$$

As $J^c(y)\tilde{t}(x)$ is always greater than 0, estimated transmission $\tilde{t}$ is smaller than its actual value. Also we known by $J(x) = \frac{I(x) - A}{\max(t(x), t_0)} + A$, for most of the pixels, becase of $I(x) - A$ is less than 0, and also $\max(t(x), t_0)$ is smaller, so the result is smaller than its actual value. That is the reason why defogging image gives a feeling of dim. The main reason is that the transmission $\tilde{t}$ is estimated smaller, so this paper proposes an amendment transmission for the purpose of adjusting brightness of the image. Specific formula is the following:

TABLE I.TIME-CONSUMING COMPARISON

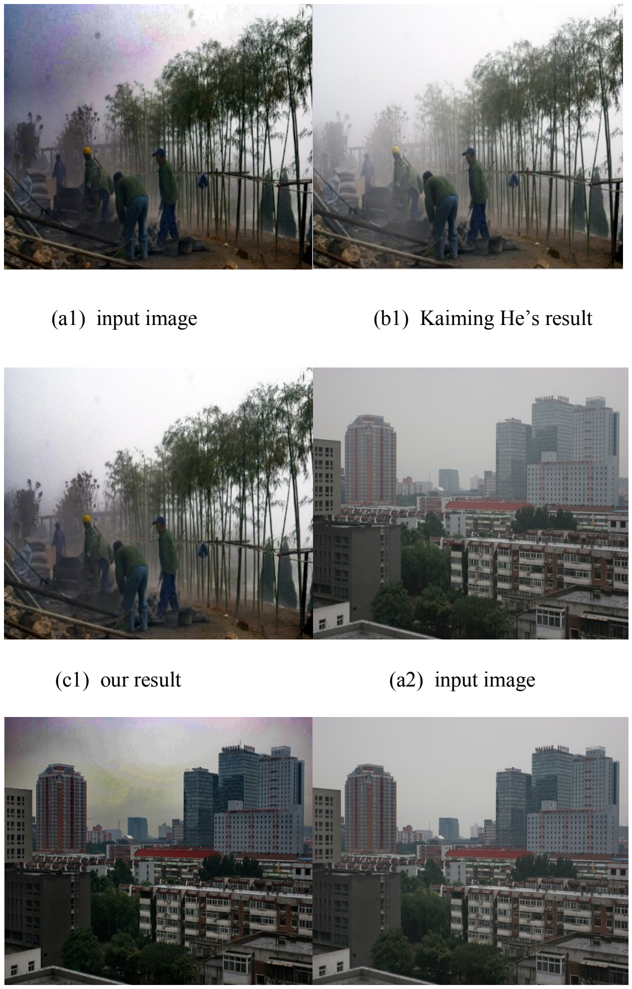
| | Traditional Dark Channel Prior algorithm | Improved Algorithm |
|---|---|---|
| Time consuming（s） | 18 | 0.39 |

$$\tilde{t}(x) = 1 - \min_{c \in \{r,g,b\}} \left( \min_{y \in \Omega(x)} \left( \frac{I^c(y)}{A^c} \right) \right) + p \quad (17)$$

where the reference range of $p$ is between 0.08- 0.25. Experiment proves it's a simple and effective way to improve image quality.

### *C. Improved Algorithm Applicability*

For most outdoor image, experiments show that the dark channel prior has some good effect to life, but it also has its limitations. When the scene objects are inherently similar to the atmospheric light and no shadow is cast on them, so the dark channel prior is invalid. Consequently, in terms of the robustness of the algorithm, we should improve that the algorithm in order to deal with the haze image of different scenes.



(a1) input image (b1) Kaiming He's result

(c1) our result (a2) input image

(b2) Kaiming He's result (c2) our result

Fig. 3. Haze removal results comparison.

Beginning with the algorithm of estimating the atmospheric light $A$ , when the image has a bright area, $A$ falls in these bright regions basically. So the dark channel prior is not available for these regions, the transmission map is not correct. Therefore, we need to weaken these bright areas to defog. In order to distinguish between bright areas and dark channel areas, we introduce a parame $K$. For image $I$ , when $|I - A| \le K$ , we identify that the region is bright area and the region needs calculate the transmission again; when the $|I - A| > K$ , we identify that the region meets the dark channel prior and the transmission in the region remains original. This paper redefine the equation (10) is as follow. Where a typical value of $K$ is 50.The ideological nature of (18) is that: for bright region, instead of the defogging, we directly give the original value. And for other areas we use the dark channel prior to implement haze removal. Experiments sho-

$$J(x) = \begin{cases} I(x) & |I(x) - A| \le K \\ \dfrac{I(x) - A}{\max(t(x), t_0)} + A & |I(x) - A| > K \end{cases} \quad (18)$$

w how that the improved algorithm can effectively improve t he adaptability. When the image has a large bright area, we can have relatively good results and do not produce distortion in the case.

## IV. EXPERIMENTAL RESULTS AND ANALYSIS

### *A. Haze Removal Results Comparison*

Haze removal based on the same single picture using the traditional Kaiming He's Dark Channel Prior and our improved algorithm is shown in Figure 3.We can see clearly that the picture processed by traditional Dark Channel Prior is dimmer and there is clear distortion in the sky region. However, our image is brightness with no distortion in the sky. Thus we get a better visual effect of the image.

### *B. Algorithm Efficiency Comparison*

We process the 600*400 pixel image of buildings shown in Figure 3 using traditional Dark Channel Prior algorithm and our improved algorithm. Table 1 show their time-consuming.

## V. CONCLUSION

In this paper, we study the dominant haze removal algorithm-Dark Channel Prior and improve the algorithm by replacing the time-consuming soft matting part with fast bilateral filter to get higher efficiency. Moreover we analysis the reason why traditional algorithm leads to dim image after haze removal and propose our improved transmission rate formula in order to get better visual effects of the image after dehazing. On this basis, taking into account that the Dark Channel Prior rule is not suitable for sky area, we decide to process this region with weaker method to improve the adaptability of the algorithm. The experimental results show that both visual effect and computing speed have been improved significantly.

## REFERENCES


[1] S.G. Narasimhan and S.K. Nayar, "Chromatic framework for vision in bad weather," in *Proceedings of IEEE Conference on Computer Vision and Pattern Recognitio*n, New York, USA, pp. 598-605, 2000.

[2] S.G. Narasimhan and S.K. Nayar, "Vision and the atmosphere," *International Journal of Computer Vision*, vol. 48, no. 3, pp. 233-254, 2002.

[3] Y.Y. Schechner , S.G. Narasimhan and S.K. Nayar, " Polarization-based vision through haze," *Applied Optics,* vol.42 , no.3, pp. 511-525, 2003.

[4] Y.Y. Schechner ,S.G. Narasimhan and S.K. Nayar," Instant dehazing of images using polarization," in *Proceedings of 2001 IEEE Conference on Computer Vision and Pattern Recognition,* Washington. DC,2001, pp. 325-332.

[5] S. Shwartz, E. Namer, and Y.Y. Schechner, " Blind haze separation" , in *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, Washington. DC, 2006, pp. 1984-1991.

[6] S.G. Narasimhan and S.K. Nayar,"Contrast restoration of weather degraded images," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 25, no. 6, pp. 713-724, 2003.

[7] R . TAN, "Visibility in bad weather from a single image," in *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition,* Washington. DC, 2008, pp. 2347-2354.

[8] R . Fattal, "Single image dehazing," *ACM Transactions on Graphics*, vol. 27, no. 3, pp. 721-729, 2008.

[9] H.E . Kaiming, J. Sun, and X.O. Tang, "Single image haze removal using dark channel prior," in *Proceeding of IEEE Conference on Computer Vision and Pattern Recognition*, Washington. DC, 2009, pp. 1956-1963.
[10] C. Tomasi and R. Manduchi, "Bilateral filtering for gray and color images," *in Proceedings of the international conference on computer vision*, New York: IEEE press.
[11] P. Sylvain and D. Fredo, "A Fast Approximation of the Bilateral Filter Using a Signal Processing Approach," *Proceedings of International Journal of Computer Vision*, vol. 81, pp. 24-52, 2009.