Improve Transmission by Designing Filters for Image Dehazing

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***Abstract*—Image haze removal techniques have a promising application prospects. However, color distortion by excessive dehazing is a common problem especially for images containing light color surface objects. To solve this problem, an improved image dehazing method based on dark channel prior with color fidelity is proposed in this paper. First, filters (Sobel operator and mean filter) are used to refine the initial transmission map estimated from the dark channel prior. Second, a piecewise constrained function is proposed to keep color fidelity. Experimental results on real world images show that the approach is effective in haze removal and preventing the color distortion from excessive dehazing. Preferable results of recovered images with bright and realistic colors and enhanced details are achieved.**

Keywords-color fidelity; sobel operator; dark channel prior; transmission optimization; single-image dehazing

I. INTRODUCTION

HAZE is a slight obscuration of lower atmosphere and it is a common weather phenomenon which is caused aerosol consisting of suspended droplets and particle in the atmosphere. Owning to light scattering from particles, the atmospheric transparency degrades. Poor visibility caused by haze, badly disturbs people's normal life. Images captured in the hazy weather are often difficult to be recognized by humans or computers. Hazy images have lower contrast and they are fuzzier than ideal images. The degradations work against systems for which visibility is important. These include applications such as surveillance, remote sensing, object recognition, etc. Therefore, haze removal techniques for digital images have a wide range of applications.

In earlier research, methods based on image enhancement usually aimed at improving the contrast of a hazy image without considering any physical model, for instance, histogram equalization [1], wavelet analysis [2] and Retinex [3]. Recent haze image restoration algorithms are based on atmospheric scattering models. Estimating arguments in atmospheric scattering model and obtaining data by imaging equipment, it is feasible to obtain recovered images. He *et al*. [4] proposed the dark channel prior (DCP) algorithm, estimating transmission and then using guided filter [5] to refine transmission map. A shortcoming is that DCP might not satisfy with some particular images when some objects in the image have a color close to the sky. Zhang *et al*. [6] computed an object and distance transmission map from the improved optical model based on depth estimation. Gibson *et al*. [7] presented an approach using adaptive Wiener filter to optimize the estimate of the amount of fog. Meng *et al*. [8] used the weighted contextual constraints on the scene transmission. Zhu *et al*. [9] proposed a novel linear color attenuation prior to recovering the depth information, according to the difference between brightness and saturation. Lai *et al*. [10] proposed two objectives for scene priors, including locally consistent radiance and context-aware transmission, to get the optimal transmission map. Cai *et al*. [11] utilized the DehazeNet which connects priors in existing dehazing method and proposed Bilateral Rectified Linear Unit (BReLU) as a non-linear activation function to achieve preferable results. Wang *et al*. [12] calculated the atmospheric light value and constructed a transmission map by using a multi-scale retinex with color restoration (MSRCR) algorithm to recover the haze image. Guo *et al*. [13] improved the accuracy of atmospheric light by the Gaussian-based DCP and used a fusion weighting function to refine transmission map.

These methods are effective in image haze removal but they may cause color distortions by excessive dehazing. DCP-based methods will suffer block artifacts without transmission optimization. Moreover, light color surface objects in the image may be mistakenly regarded as fog and haze areas and then recovered with untrue colors. While restoring an image by color attenuation prior tends to be darker than the original image when the image has low contrast. For solving these problems, in this paper, we have proposed a color fidelity dehazing algorithm. Sobel Operator is used to detect edge and refine the transmission. Besides, a piecewise function is taken to eliminate color distortion on bright surfaces. Further, a constrained low bound parameter is proposed to protect the light color objects in the image from over-dehazing. Experimental results show that the proposed method effectively removes the haze from images with details enhanced, the block artifacts restrained, the brightness of the overall image increased as well as light color objects area preserved.

II. BACKGROUND

A. *Atmospheric Scattering Model*

In computer vision field, the atmospheric scattering model is widely used in dealing with hazy images, described by the following formation [14]:

$$\mathrm{I(x) = J(x)t(x) + A\big(1 - t(x)\big)} \tag{1}$$

where $I(x)$ is a hazy image, $J(x)$ represents scene radiance, A denotes atmospheric light, and t is transmission of haze. The transmission is related with distance, which can be expressed as:

$$\mathrm{t(x)} = e^{-\beta d(x)} \tag{2}$$

For getting scene radiance $J(x)$ from (1), besides known $I(x)$, we need to estimate A and $t(x)$. $J(x)$ can be obtained by:

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

Restricting $t(x)$ to a lower bound t_0 means a certain small amount of haze remains in very dense haze regions. He [4] set t_0 to 0.1. The final recovered image $J(x)$ is given by:

$$\mathrm{J(x)} = \frac{I(X)-A}{\max(t(x),t_0)} + A \tag{4}$$

B. Dark Channel Prior

He *et al*. [4] proposed the computation of DCP from statistical data of a captured image: there are pixels with a low value on one color channel at least in most non-sky patches. The dark channel of pixel x is given by:

$$J^{dark}(x) = min_{c\in\{r,g,b\}}(min_{y\in\Omega(x)}\big(J^c(y)\big)) \tag{5}$$

where, J_C is a color channel of J and Ω(x) is a local patch around x. After denoting transmission map as $t(x)$, making both sides of (1) with min operation and RGB channels, we have:

$$\min_C(\min_{y\in\Omega(x)}(I^C(y))) = t(x)\min_C(\min_{y\in\Omega(x)}(J^C(y))) + (1-t(x))A^C \tag{6}$$

In the haze-free local, the $J_{dark}(x)$ should tend to zero, and A_C is always positive. The transmission of sky regions tends to zero. For handling both sky and non-sky regions, a constant parameter ω(0≤ω≤1) is introduced into Equation:

$$\mathrm{t(x)} = 1 - \omega\min_c(\min_{y\in\Omega(x)}(\frac{I^C(y)}{A^C})) \tag{7}$$

He *et al*. [4] suggest the patch size Ω(x) 15×15 and fix ω =0.95. But the problem is that there are halo and block artifacts in edges of the recovered images. So, in the next section, we proposed techniques to solve the problem.

III. TECHNICAL APPROACH

DCP-based haze removal method proposed by He *et al.* [4] is effective and efficient in haze image recovery but suffers from block artifacts and color distortions for images with heavy haze or light color objects. Aiming at solving these problems of DCP, we proposed an improved DCP-based algorithm with color fidelity. First an initial transmission map is estimated by DCP with the patch size Ω(x) for computing dark channel map 5×5. Second, Sobel operator and mean filter are used to detect and smooth edges, respectively, to refine the transmission map. Third, a piecewise and constrained function is used to optimize a parameter t_0 according to the refined transmission map and atmospheric light A. Lastly, a haze removed image is estimated. The complete flowchart of the dehazing algorithm is shown in Figure 1.

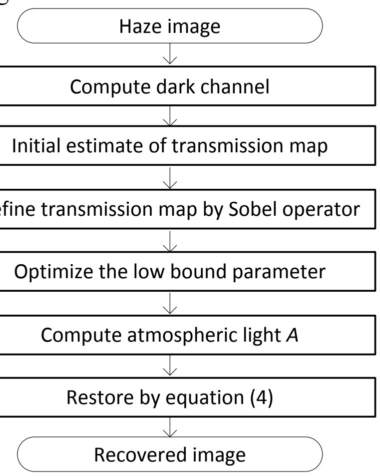


Figure 1. Flowchart of the proposed framework.

A. Sobel Operator

On both side of edges, the transmission changes obviously, so certain patch size Ω(x) for computing dark channel and the transmission map. Therefore, we take two measures to solve this problem. First, we change the patch size Ω(x) from 15×15 to 5×5. For further restraining block artifacts, we detect edges in transmission map using Sobel operator [15] with four directions as shown in Figure 2 and then use mean filter to smooth edges.

$$\begin{bmatrix}1&0&-1\\2&0&-2\\1&0&-1\end{bmatrix}\begin{bmatrix}1&2&1\\0&0&0\\-1&-2&-1\end{bmatrix}\begin{bmatrix}2&1&0\\1&0&-1\\0&-1&-2\end{bmatrix}\begin{bmatrix}0&1&2\\-1&0&1\\-2&-1&0\end{bmatrix}$$

Figure 2. Sobel Operator with four directions.

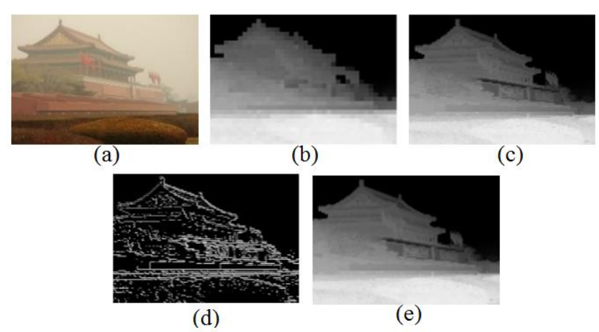


Figure 3. Optimize the transmission map by Sobel Operator. (a) input image. (b) He *et al.'s* [4] initial transmission map: Ω(x) 15×15. (c) our initial transmission map: Ω(x) 5×5. (d) Sobel Operator detecting edges. (e) using mean filter smooth edges.

Figure 3 describes the overall process. After comparing Figure 3 (b) and (c), the block artifacts decrease because of the smaller blocks. Figure 3(d) shows that the major edges of Figure 3 (c) are detected. Edges in Figure 3(e) are a little smoother than those in Figure 3(c). The experimental results indicate that this method is a great help in solving block artifact problem.

B. Piecewise Function of Lower Bound Parameter

We can get an effective dehazing picture by using Sobel operator, especially in the thick fog area. However, the thin fog area or light color objects will be dehazed excessively with color distortions. The lower the low bound parameter t_0, the more evident the color distortion. But too large t_0 will lead to insufficient dehaze result. So, a piecewise function of t_0 is applied according to range of different $t(x)$.

After several experiments, we can find facts about low bound parameter setting. First, distant objects with thick fog can be recovered best when setting the minimum value of t_0 to be 0.5. Second, assigning t_0=0.7, when $t(x)$ is greater than 0.7, it can make thin fog area keep correct color. The piecewise function is written as follows:

$$t_0(x) = \begin{cases} 0.5 & 0 \le t(x) < 0.45 \\ t(x) + \frac{0.7 - t(x)}{5} & 0.45 \le t(x) < 0.7 \\ 0.7 & 0.7 \le t(x) \end{cases} \quad (8)$$

The graph of function (8) is drawn in Figure 4. The range of t_0 is from 0.5 to 0.7, and it can control the brightness in a reasonable range. The results suggest that setting piecewise function of t_0 is useful to keep color balance.

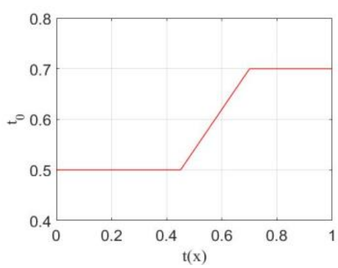


Figure 4. Graph of equation (8).

C. Improving Light-Color Area

Images appear brighter and the color is more accurate by piecewise function of t_0. But some $t(x)$ values of the surface area of light color objects often have a low value, because such objects will be regarded as thick fog by mistake. Hence, the problem of excessive dehazing still exists in the light color area by piecewise function.

As we known, the Atmospheric Scattering Model presents an idea that $t(x)$ is connected to distance. The farther the distance, the larger the transmission, therefore, the larger the value that t_0 should be set, and vice versa. It can be concluded that t_0 in a close shot is never smaller than t_0 in a distant view. So, we take this conclusion as a constraint condition. The 2-D mathematical formula is as follows:

$$t_0(x, y) = \max(t_0(x, y), t_0(x-1, y)) \quad (9)$$

Adding this constraint condition, t_0 of light color objects does not obtain a low value because of especially low $t(x)$. Therefore, this kind of objects like rocks and white walls will not be judged as thick mist. The method ensures that the light-color objects will not be dehazed excessively.

IV. EXPERIMENTAL RESULTS

The proposed algorithm was developed and tested in MATLAB 2016. Some key parameters in our algorithm are: atmospheric light A is the maximum of RBG channels and ω is 0.95 in (7). The patch size of dark channel $\Omega(x)$ is 5×5 pixels. The t_0 is according to (8) and $t(x)$ is from (7). Then the scene radiance is recovered through (4). The experimental results and analysis are presented below.

Because the haze images are derived from real-world not synthetic, it is difficult to compare original images. Three indices are used to evaluate the quality of a recovered image, including Contrast (σ^2), Information Entropy (H) and Mean Gradient (GMG), respectively defined by equations [10-12]. The contrast is showed by gray variance. Information entropy is the measure of information containing in an image. Average Gradient reflects the changes of edges in images.

$$\sigma^2 = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} [I(i,j) - \mu]^2, \ \ \mu = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} I(i,j) \quad (10)$$

$$\mathrm{H} = \sum_{0}^{L-1} \frac{H_r}{m \times n} log \frac{H_r}{m \times n} \quad (11)$$

$$\mathrm{GMG} = \frac{1}{(m-1)(n-1)} \sum_{i=1}^{m-1} \sum_{j=1}^{n-1} \sqrt{\frac{\Delta I_x{}^2 + \Delta I_y{}^2}{2}} \quad (12)$$

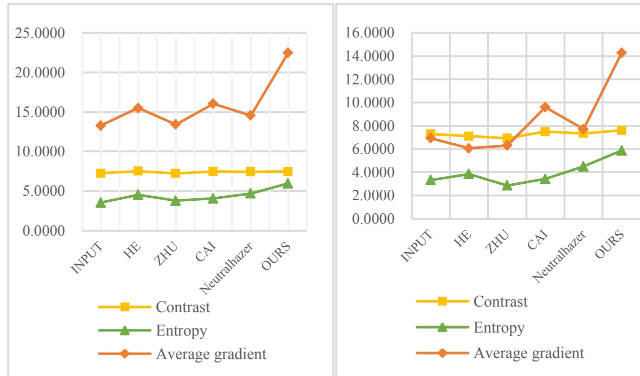
where, $I(i, j)$ represents an image and $m \times n$ is the size of the image. L is maximum gray scale. The H_r is the number of pixels whose gray scale value is r. $\triangle I_x$ and $\triangle I_y$ is first-order gradient in direction of x axis and y axis, respectively.

He *et al*. [4] used DCP combined with guild filter to remove haze from hazy images. Zhu *et al*. [9] proposed color attenuation prior for haze removal from a single input image. Cai *et al*. [11] used an end-to-end system for single image haze removal. Neutralhazer[16] is a plug-in of Photoshop for haze removal. Our method used Sobel operation and introduced constrained function on the basis of DCP. The comparison of the above-mentioned four methods is presented in Figures 5-8.

(a) Input image (b) He [4] (c) Zhu [9] (d) Cai [11] (e) Neutralhazer [16] (f) the proposed

Figure 5. Results of Tiananmen image and Mountains image.

We compared our method with He [4], Zhu [9], Cai [11] and Neutralhazer [16]. Figure 5 shows the input and recovered output images of different algorithms. The unusual dark yellow in the sky area in Tiananmen image in Figure 5(b) indicates there is relative color distortion in He's result. Recovered images of Zhu's method in Figure 5(c) are generally darker than the others. Cai's output images in Figure 5(d) keep much fog and still look hazy which can be seen clearly in the mountains image. Results by Neutralhazer in Figure 5(e) is darker than our results especially in the sky region. Comparatively speaking, recovered images by our method in Figure 5(f) are clearer and brighter than the others without color distortion. From Figure 6, we can see that the contrast index for five results has remained more or less constant. Low contrast will affect the brightness of an image and make the image lose details. But contrast that is too high will lead to color distortion. So, our method benefits by keeping a sense of clarity and color fidelity. The entropy and average gradient have also been increased. It means that our results have more details especially in edge regions. The indices show some advantages over Neutralhazer. Our method can also be used as a kind of software or a plug-in for image processing applications.

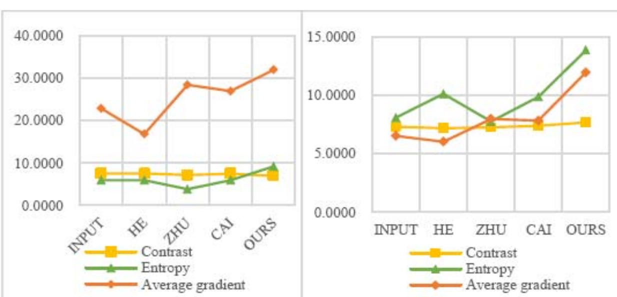


(a) Indices of Tiananmen image (b) Indices of Mountains image

Figure 6. Index comparisons of haze removal algorithms.

(a) Input image (b) He [4] (c) Zhu [9] (d) Cai [11] (e) the proposed

Figure 7. Results of buildings image and cliff image.



(a) Indices of buildings image (b) Indices of cliff image

Figure 8. Index comparisons of haze removal algorithms.

Figure 7 shows images which contain lightly colored surface objects such as white walls and rocks. Excessive dehazing will lead to a color distortion as a result of mistakenly regarding these light color objects as the fog and haze area, which can be observed in Figure 7(b) and 7(c). Our results in Figure 7(e) restrained color distortion and keep the walls and rocks in original white and bright conditions. Even though for the building with the orange and white exterior wall in the distant region in the upper buildings image, we can clearly see the white walls and dark windows in the building. The experiment results show that our method is effective in haze removal with color fidelity especially for images containing light color objects. From Figure 8, the maximum entropy and average gradient demonstrates that the proposed method has advantages in enhancing details.

(a) Input image (b) He [4]
(c) Zhu [9] (d) Cai [11]
(e) Neutralhazer [16] (f) the proposed

Figure 9. Results of vehicle images.

As another example of reading license plate in the presence of haze is shown in Figure 9. It shows that our method is capable of being used to preprocess hazy images for a license plate recognition system.

V. Conclusion

In this paper, a novel and improved algorithm is proposed based on DCP. This algorithm mainly aims at optimizing the transmission map and preserving color fidelity. Qualitative and quantitative comparisons indicate that preferable output results are obtained by our algorithm with clearer and brighter recovered images with more details and colors closer to the real scene. An image processing tool based on the proposed algorithm has been developed to remove haze in a single image. This tool can serve as a plug-in or preprocessing module for other applications such as outdoor environment surveillance systems and object recognition applications operating in the hazy weather.

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