A DEHAZING ALGORITHM USING DARK CHANNEL PRIOR AND CONTRAST ENHANCEMENT

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ABSTRACT

This paper proposes a dehazing algorithm based on dark channel prior and contrast enhancement approaches. The conventional dark channel prior method removes haze and thus restores colors of objects in the scene, but it does not consider the enhancement of image contrast. On the contrary, the image contrast method improves the local contrast of objects, but the colors are often distorted due to the overstretching of contrast. The proposed algorithm combines the advantages of these two conventional approaches for keeping the color while dehazing. For this, an optimization function is proposed to balance between the contrast and colors distortion, where the contrast measure follows the conventional image statistics and the hue component is used to constrain the color changes. According to the experimental results, the proposed approach compensates for the disadvantages of conventional methods, and enhances contrast with less color distortion.

Index Terms— dehazing, image enhancement, image restoration, dark channel prior, contrast enhancement

1. INTRODUCTION

The outdoor scene is often degraded due to fog, rain or snow, which hinder the clear observation of objects in the scene and also degrades the performance of computer vision tasks such as object detection, tracking and recognition. Hence there have been much efforts for the dehazing, i.e., haze removal. In the early works of dehazing, more than one image is used or different polarization filters are used [1, 2]. Also, more than one image captured in different weather conditions are used in [3, 4, 5]. In the case of [6], additional depth information is used to remove the haze.

Recent researches mostly focus on single image dehazing, which usually require the depth information of the scene or some kind of strong assumptions on haze and haze-free images. For example, Fattal [7] assumed that the albedo of a local patch has the same vector direction. Tan [8] assumed that haze-free image has better contrast compared to the hazy image. More recently, dark channel prior assumption was proposed to estimate the depth information based on the comparison between the hazy and clean image [9], which is proved to be a very powerful prior in single image dehazing. There is also a contrast enhancement approach for dehazing [10], which is also quite effective in removing the haze. However, it seems that these recent works also have some limitations in that the contrast enhancment method shows some color distortion and the dark channel prior method does not improve the contrast while the color distortion is small.

Hence in this paper, we attempt to derive an algorithm that combines the advantages of dark channel prior and contrast enhancement method. Specifically, we design an optimization algorithm that balances between the contrast measure and dark channel measure, so that the contrast of haze image is improved with less color distortion. Experimental results show that the proposed method finds more plausible transmission map and thus generates more contrasted dehazing results than the conventional dark channel prior method, with less color distortion than the contrast enhancement method.

2. RELATED WORKS

In this section, we describe the existing works that are closely related with the proposed method.

2.1. Optical moedel of hazy image

The approximate model of hazy image is described as [7]

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

where $I(x)$ is the observed intensity at pixel x, $J(x)$ is the original haze-free intensity, A is the atmospheric light for the whole image pixels, $t(x)$ is the medium transmission that can be considered a kind of blending factor to mix the atmospheric light and the original object color. Usually, the transmission $t(x)$ is decreased as the distance of the object to the camera increases. The dehazing is to restore the original image color $J(x)$ by finding A and $t(x)$ at each x.

2.2. Dark Channel Prior

The dark channel prior assumption is from the observation that at least one of color channel values (RGB) is often close to zero in some objects in a haze-free image [9]. The dark channel in an image J is defined as

$$J^{dark} = \min_{y \in \Omega(x)} \{ \min_{c \in (R,G,B)} J^c(y) \}, \quad (2)$$

where J_{dark} is the dark channel of J, J^c is the color channel, and $\Omega(x)$ is the patch centered at x. If J is a haze-free image, the dark channel of J is assumed to be zero. Then the transmission is determined as

$$t(x) = 1 - \min_{y \in \Omega(x)} \left\{ \min_{c \in (R,G,B)} \frac{I^c(y)}{A^c} \right\} \quad (3)$$

and we can restore $J(x)$ with an appropriate estimation of A.

2.3. Local contrast enhancement

Kim [10] et al., use the contrast enhancement formulation to find the transmission parameter in a local patch. They measure the strength of contrast in terms of the histogram uniformity and intensity variance as [10]

$$\begin{aligned} f_{uni}(t) &= \sqrt{\frac{1}{N} \sum_{i=0}^{255} \left(\frac{1}{256} - \frac{h_i(t)}{N} \right)^2} \\ f_{std}(t) &= \sqrt{\frac{1}{N} \sum_{p=1}^{N} \left(J_{p,Y} - \bar{J}_Y \right)^2} \end{aligned} \quad (4)$$

where $f_{uni}(t)$ and $f_{std}(t)$ are cost functions to measure the histogram uniformity and the standard deviation of local intensity for a transmission value t in a patch. In (4), $h_i(t)$ is the luminance intensity histogram in the patch, and N is the total number of pixels in the patch. $J_{p,Y}$ and $\bar{J}_Y$ are luminance intensity value and the intensity mean in the patch respectively. Finally, the joint cost function to find transmission parameter is combined as

$$f_{cont}(t) = f_{uni}(t) - f_{std}(t). \quad (5)$$

The transmission parameter is determined when the cost function is minimized, i.e., the local contrast is maximized in the sense of histogram uniformity and largest intensity variance.

3. PROPOSED METHOD

As mentioned previously, the contrast enhancement method does not consider the restoration colors. This method makes the colors highly visible by contrast stretching, and hence sometimes show color distortion and unexpected color shift. On the other hand, the dark channel prior method restores the image colors, but does not consider the contrast or visibility of objects.

In this paper, we propose a dehazing algorithm which considers both the contrast enhancement and color restoration. For this, we define a cost function to find the transmission map, which combines the contrast enhancement and dark channel prior assumption. To be precise, we define a joint cost function to estimate the transmission parameters:

$$f(t) = \alpha f_{cont}(t) + (1 - \alpha) f_{dark}(t) \quad (6)$$

where $f_{cont}(t)$ and $f_{dark}(t)$ are measurements of the contrast and dark channel respectively, and α is a weight that can control color distortion. The first term $f_{cont}(t)$ is defined based on (4) as

$$f_{cont}(t) = a f_{uni}(t) - b f_{std}(t), \quad (7)$$

where a and b are empirically determined to adjust the histogram uniformity and variance. In our experiments a is set to 0.2 and b to 5 in all the experiments. The second term in (6) is modeled as

$$f_{dark}(t) = \sqrt{\frac{1}{3N} \sum_{c \in (R,G,B)} \sum_{x=1}^{N} (J^c_{dark}(x) - J^c_t(x))^2}, \quad (8)$$

where $J^c_{dark}(x)$ is a patch from a dehazed image by the conventional dark channel prior method, and $J^c_t(x)$ is the dehazed image patch by the proposed method. It can be considered root mean square error between dark channel prior and proposed dehazed image. If the transmission has similar value to the conventional dark channel prior result, $f_{dark}(t)$ has low value, which also means that the result has small color distortion. In this case, we may put more emphasis on the contrast rather than the color distortion, and thus increase the weight α in eq. (6) and vice versa. Based on this observation, we define the weight α in (6) as a function of hue shift,

$$\alpha = \exp\left\{ -\frac{(f_{hue}(t))^2}{2\sigma_\alpha^2} \right\}, \quad (9)$$

where $f_{hue}(t)$ measures the statistical hue shift between the dehazed image by dark channel prior and that by the proposed transmission as

$$f_{hue}(t) = \sqrt{\frac{1}{N} \sum_{x=1}^{N} d_H \left(H(J_{dark}(x)) - H(J_t(x)) \right)^2}, \quad (10)$$

where $H(\cdot)$ means the hue component. The hue distance measure $d_H(h)$ is defined as

$$d_H(h) = \begin{cases} h, & \text{if } h < 180 \\ 360 - h, & \text{otherwise.} \end{cases} \quad (11)$$

The transmission value that minimizes the cost function in eq. (6) is estimated for the given input, where Fig. 1 shows an example of cost function in gray scaled transmission values. It can be seen that the optimal transmission value for each method is different, specifically the optimal transmission value of dark channel prior is around 230, but that of contrast enhancement around 140. By combining these two graphs as in eq. (6), the optimal transmission of the proposed method is

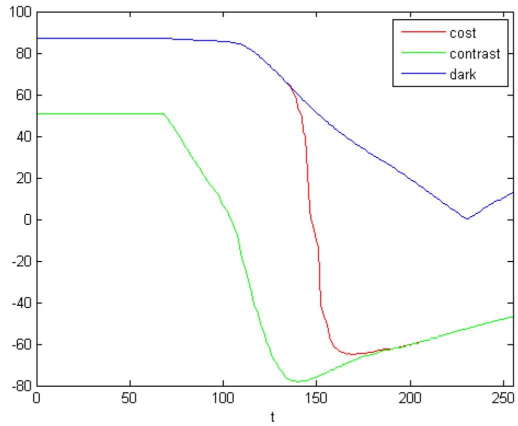


Fig. 1. The graph of cost functions in eq. (6) for finding the optimal transmission value. The minimum is obtained by combining the costs of dark channel prior and contrast enhancement.

found to be 160, which compensates for the color distortion and improves the contrast in the dehazed image.

Finally, we refine the transmission map using a smoothing filter. The transmission map has halo effect problem, because we assume that the transmission is a constant in the patch. To alleviate this problem, we refine the transmission map using the edge information of hazy image. We use guided image filter [11], where the parameters of the filter are set as $r = 20$, $\alpha = 10^{-3}$.

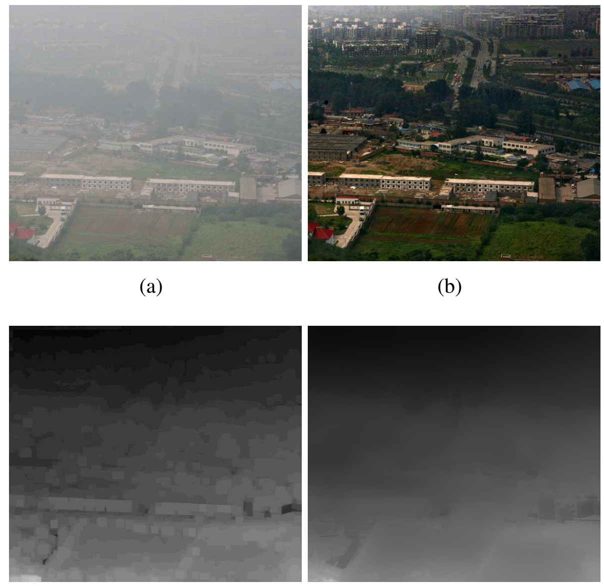
4. EXPERIMENTAL RESULTS

We use various outdoor images to test the proposed algorithm, and set the parameter as patch size= 15×15, and $\sigma_\alpha = 10$ for every experiment. When minimizing the cost function, we determine the optimal transmission among $0, 1/32, 2/32, ..., 1$. Also, we estimate the atmospheric light using the method in [9].

Fig. 2 shows the transmission maps and dehazed image for a test image by the proposed method. We also compare the proposed algorithm with the conventional algorithms: dark channel prior [9] and local contrast enhancement methods [10]. Fig. 3 shows the comparison of 3 methods, where it can be observed that the proposed method improves the contrast with less color distortion. As we mentioned before, the results by dark channel prior method are sometimes not clear, and those by contrast enhancement method have some color distortion caused by over-stretching.

5. CONCLUSION

We have proposed a dehazing algorithm that considers both contrast enhancement and color distortion. This is achieved by combining the conventional dark channel prior and contrast enhancement measure. Specifically, we derive a cost function for finding an optimal transmission map that balances between the enhancement and color distortion. According to the experimental results, the proposed approach compensates for the disadvantages of conventional dark channel prior method and contrast enhancement approaches, i.e., it enhances the contrast of objects with less color distortion.



(a) (b)

(c) (d)

Fig. 2. A result by proposed method. (a) input image, (b) dehazed image, (c) transmission map, (d) refined transmission map by [11]

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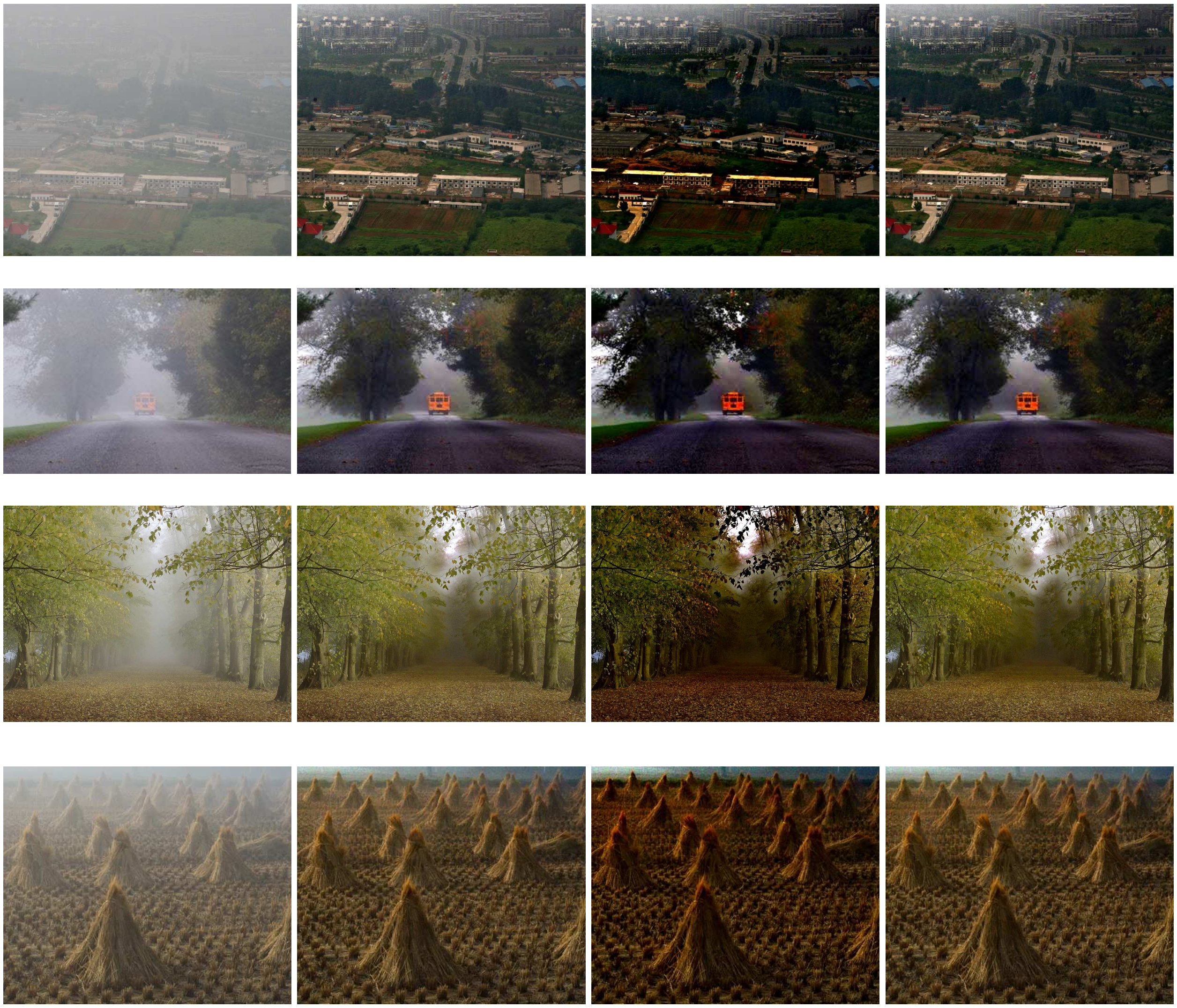

(a) (b) (c) (d)

Fig. 3. Comparison of dehazed images, (a) input image (b) results by dark channel prior method [9] (c) results by contrast enhancement method [10] (d) results by proposed method.

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