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Improving Dark Channel Prior for Single Image Dehazing

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ABSTRACT

This paper proposes an improved dark channel prior for removing haze from images. Dark channel prior is an effective method for removing haze. Dark channel is an image in the same size as the hazy image which is obtained by dividing the RGB images into windows and for each window, the minimum of each R, G and B channels are calculated. Then again the minimum of these three values is calculated and is replaced on all pixels in that window. For removing haze from images by dark channel prior, it is necessary to find transmission coefficient of haze and for this, airlight must be estimated. By having these factors, haze-free images can be restored. The dark channel prior method does not yield favorable results for some images, especially for those containing smooth regions. To overcome this deficiency of the dark channel prior approach, the hazy image is initially segmented into smooth and non-smooth regions in this paper. Then for removing haze from smooth regions, the Gamma correction approach is used for contrast enhancement. Finally, for non-smooth regions, depending to the severity of haze, dark channel prior might be applied several times. The subjective and objective image quality assessments attest superiority of the proposed method compared to dark channel prior in haze removing.

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1. INTRODUCTION

Due to the suspended particles in the atmosphere which cause light scatter, outdoor images may contain fog, mist or haze. The visibility of the scene is reduced in these images and color shift may occur [1]. Hence hazes need to be removed for extracting desirable information and features from the images. There are two general methods for this purpose: multiple images methods and single image methods. The former methods have several shortcomings, namely; their additional need of information from multiple images, their ineffectiveness for hazy images, and their preparation difficulty. The latter methods do not require any additional information about the image. What follows is the description of some of the pertinent methods of the aforementioned categories.The multiple images methods like those based on polarization [2, 3] use multiple images taken from different degrees of polarization. In some literature [4-6] haze is removed from the images using images obtained from the same scene at different weather conditions. The other methods of this category are depth-based methods [7, 8], which need information of the depth from the user for removing haze.

Results from a number of existing single image based methods are shown in Figure 1 for comparison. In the single image methods [9], it is assumed that the restored image has more contrast compared to the hazy image. Hence, they try to remove haze by maximizing local contrast in the restored image. As can be seen in the white rectangle inFigure 1(b), this method is not effective in restoring hazy image containing natural colors. In the literature[10] transmission coefficient of the suspended particles is estimated by considering reflections inthe scene. Then, the image is restored by using this transmission coefficient. This method has two problems, it isn't suitable for dense haze and needs enough color information from the image. Due to these deficiencies we can see color integration and distortion for the woman'shair in the rectangle in Figure 1(e). The authors in another work [11] proposed a dehazing

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algorithm based on dark channel prior (DCP). Following this approach, it is assumed that at least one color channel has very low intensities within a window in a haze-free image. Hence, haze-free image can be restored by estimating transmission coefficient and airlight.The shortcoming of this method, as can be seen from the area shown by the rectangle in Figure 1(h), is the blocking effect on the smooth areas. In another study [12] the guided filter dark channel prior (GDCP) was used to improve DCP. The problem of this method, shown by the rectangle in Figure 1(k), is the blurring effect especially around edges of the buildings. DCP is the most popular single image dehazing method which has rather favorable results in this context.

(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l)

Figure 1. Limitation of the current dehazing methods: (a,d,g,j)hazy images; results of haze removing using the existing approaches ((b) the method in [9], (e) the method in [10], (h) the method in [11], (k) the method in [12])and(c, f, i, l)results of haze removing approach in this paper. (The images in b, e, h, k were downloaded from pages:http://research.microsoft.com/en-us/um/people/kahe/ cvpr09/comparisons.html and http://www.cs.huji.ac.il/_raananf/projects/defog/)

(a) (b)

Figure 2. (a)An example of a hazy image and (b)its dark channel.

However, the DCP based approaches may cause blocking effect in removing haze from smooth regions. In addition, they cannot provide satisfactory results in removing haze from images suffering haze with various severity in different areas. To overcome the shortcomings, we segment the hazy image for separating smooth and non-smooth regions in this paper. For smooth areas, a simple Gamma correction approach is used to improve the contrast [13-16]. In the non-smooth regions, DCP is applied several times depending to the severity of haze.

This paper is organized as follows. In section 2, the DCP approach for haze removing is introduced. The proposed method is presented in detail in section 3. In section 4, experimental results are provided with both subjective and objective evaluations. Finally, we conclude the paper in section 5.

2. THE DCP METHOD

The authors in a previous study [11] used digital image processing technique to model hazy images. This model is defined as below:

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

where I, J, t, A, x are respectively the hazy image, the haze-free image, the transmission coefficient, the global airlight, and the image pixel. The term $A(1 - t(x))$ is the local atmospheric light, and $J(x)t(x)$ is the direct attenuation. According to the above equation, for restoring image from hazy image, two unknown parameters such as airlight(A) and transmission coefficient $(t(x))$must be estimated. There are many methods that estimate these two parameters, which DCP [11] is one of the successful methods in this context. The dark channel of the image J is given by:

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

where$\Omega(x)$ represents the local neighbors of pixel x and $J^c$is one of the color channels.

Dark channel is calculated in this way that hazy image is divided into windows (usually 15x15) and for each of these windows, one pixel is estimated as dark pixel. Then this dark pixel is replaced on all pixels in that window. For obtaining this dark pixel, the minimums in R, G and B channels are calculated. Then, again the minimum from these three channels is calculated. This is repeated for each window to obtain the dark channel of the image. For estimating transmission coefficient (t(x)) by the dark channel, the following equation is used:

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

where$\tilde{t}(x)$is the transmission coefficient for each patch. In Figure 2, it can be seen that hazy regions in dark channel image are brighter. Hence the pixel value in hazy image is larger than its value in haze-free image. Then according to Equation (4), dark channel of haze-free image tends to zero. By replacing zero on dark channel of haze-free image in Equation (3), transmission coefficient can be obtained using Equation (5).

$$\min_c(\min_{y\in\Omega(x)}(\frac{J^c(y)}{A^c}) = 0) , \tag{4}$$

$$\tilde{t}(x) = 1 - w.\min_c\left(\min_{y\in\Omega(x)}\left(\frac{I^c(y)}{A^c}\right)\right), \tag{5}$$

In the above equation $\min_c\left(\min_{y\in\Omega(x)}\left(\frac{I^c(y)}{A^c}\right)\right)$ is the normalized dark channel of the hazy image, and wis used to make the restored image more natural (0<w <1) [11]. For obtaining $\tilde{t}(x)$, the global airlightAmust be estimated. Hence the top 0.1% brightest pixels of the dark channel are selected. Then according to these pixels the highest intensities of hazy image, is taken as the airlight [11]. Then transmission image can be refined for eliminating its discontinuities [12]. Finally the haze-free image can be observed from Equation (1) asshown below:

$$J(x) = \frac{I(x) - A}{\max(t(x), t_0)} + A , \tag{6}$$

As t(x)tends to zero in images with less haze, a minimum value for transmission coefficient is considered $(t_0 = 0.1)$ [11].

3. THE PROPOSED ALGORITHM

Block diagram of the proposed methodcan be observed in Figure 3. In this diagram, to eliminate the blocking effect of smooth regions caused by DCP, we separate smooth and non-smooth regions by segmenting the hazy image. The Gamma correction method proposed elsewhere [16] is used to enhance hazy image in smooth regions. For removing haze from non-smooth regions, first we apply DCP to these regions, then we extract dark channel of the resulting image. As mentioned before, the image is hazier in the brighter areas of the dark channel. Hence we segment the dark channel into darker and brighter segments. Finally, DCP is applied to the brighter segment once again. These steps are explained in detail in the following subsections.

3. 1. PixonBased Segmentation

Because of the better cohesion of segments created by the pixonal approach as described elsewhere [13], we use this method for segmenting hazy image. A pixon in an image is a set of interconnected pixels. For obtaining these pixons, we compare the value of neighboring pixels with each other. If this value is less than a threshold, they consider as one pixon. We choose the threshold value as 20 in this paper. When all pixonsareadded together, the original image can be obtained. In other words, pixon-based image can be observed as follows:

$$IM = \cup_{i=1}^{n} P_i \, , \qquad (7)$$

where $IM$is the pixon-based image model, n is the number of pixons, P_i is a pixon, and $\cup$is the union symbol. The pixon intensity is defined as the average value of the connected pixels making up of the pixon.
After formation of pixons, the final segmentation takes place. For this purpose, the Fuzzy C-Mean (FCM) algorithm which is one of the most widely used clustering algorithms, is employed [14]. In this paper we use the FCM to divide the pixon-base image to segmented image. An example of the above-described segmentation approach can be seen in Figure 4.

3. 2. Smooth and Non-smooth Region Detection

In the previous section the hazy image is segmented into five regions. Since we use different approaches for removing haze from smooth and non-smooth regions, these five segments are created according to their texture. Texture image can be obtained as below [15]:

$$\bar{x}(i,j) = \frac{2}{(2L+1)^2}\sum_{k=-L}^{L}\sum_{l=-L}^{L} x(i+k, j+l) \, , \qquad (8)$$

$$M_T = |x(i,j) - \bar{x}(i,j)| \qquad (9)$$

where $\bar{x}$ is the local average and M_T is the localvariance. In this model, the image is windowed with the size of 2L+1 × 2L+1. Then the local average is calculated for each window according to Equation (8). Finally the texture matrix can be obtained from Equation (9). As can be conceived from Figure 5(b), the denser texture results in a larger variance. The average values of the five segments obtained from the previous section are computed using the average texture value in Equation (8). Then the area with the average texture value larger than a predefined threshold value is considered as smooth. We choose the threshold value as 2 in this paper.

3. 3. Removing Haze from Smooth Regions

Environmental illumination are very effective on the image illumination and non-uniform illuminationmay cause impairment on the captured image [16].Many devices used for capturing images generally apply a transformation, called power-low on each pixel of the image that has a nonlinear effect on luminance [17]:

$$g(u) = u^r \, , \qquad (10)$$

where $u \in [0, 1]$denotes the image pixel intensity, $r$is a positive constant introducing the Gamma value.

By passing a calibration target with a full range of known luminance values, the value of r can typically be determined experimentally [18].When the value of $r$is known, inverting this process is trivial:

$$g^{-1}(u) = u^{1/r} \qquad (11)$$

when the amount of $r$is less than one, the transformed image becomes lighter than the original image; and when the amount of $r$is greater than one, the transformed image becomes darker than the original image [19]. We choose the Gamma value as 0.7 in this paper to enhance smooth regions of hazy image.

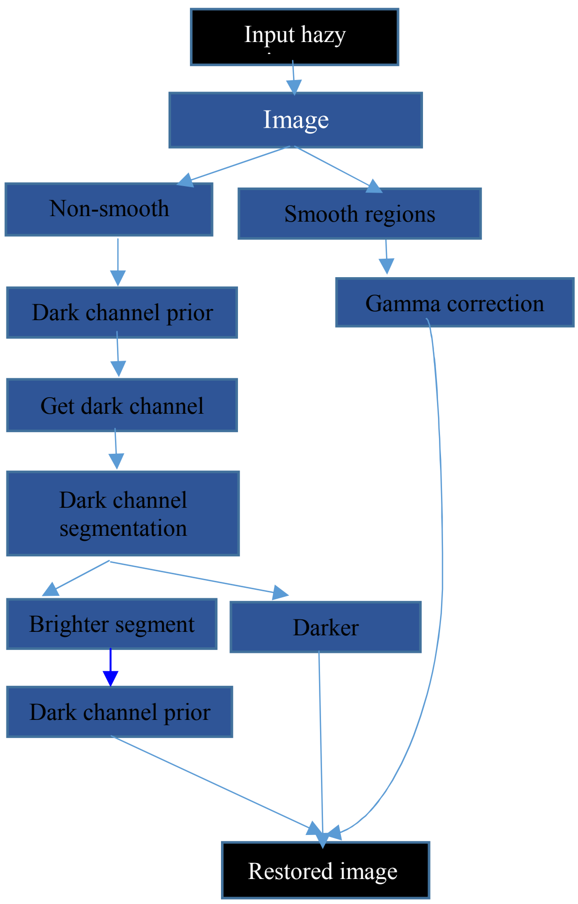


Figure 3. Block diagram of the proposed haze removing approach.

3. 4. Removing Haze from Non-smooth Regions

First the DCP is applied to the whole image which its smooth regions have been excluded. Then the dark channel of the resulting image is extracted. As mentioned before, the image is hazier in the brighter areas of the dark channel. Hence the dark channel image is segmented to the brighter and darker segments using the pixon-based approach described before. Finally the DCP is applied to brighter segment once again (see Figure 5).

4. EXPERIMENTAL RESULTS

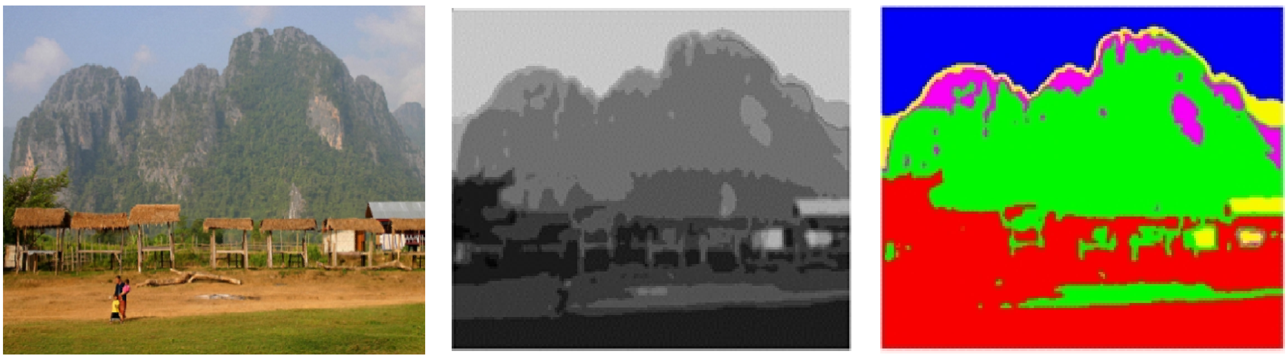
In this paper, we present a technique for improving the DCP technique in enhancing hazy images. We consider objective and subjective image quality assessments to evaluate the performance of the proposed method.

Objective methods can be used for numerically measuring the image quality. We used two factors as objective quality assessment; edges (e) which may not be seen well in hazy images and average gradient (r) after and before the restorationfor estimating visibility enhancement. These factors were estimated for both the DCP and the proposed methods applied on a number of hazy images, and the results are shown in Table 1. The larger values of e and $r$describe the better results. Table 1 shows that the proposed method has more visible edges and higher values of the average gradient for all of the images.

In subjective assessment of the proposed approach and comparing with those of the exiting approaches, we have provided the associated output results of several natural hazy images employed in the objective assessment. As can be seen in Figures 6 and 7, the image containing mountains and buildings, the DCP yields unfavorable results for improving the sky region, and causes blocking effect in these regions but there is no blocking effect in results of the proposed approach. From the images in Figures 8 and 9, it can be conceived that the proposed method provides more favorable results in removing haze from depth regions.

TABLE 1. Objective performance comparison of the proposed method with the DCP method.

	Figure	DCP	The proposed method
Edges (e)	Figure 6	0.014	0.014
	Figure 7	0.122	0.22
	Figure 8	0.11	0.2
	Figure 9	0.71	0.9
Ration of average gradient (r)	Figure 6	1.12	1.36
	Figure 7	0.99	1.23
	Figure 8	1.03	1.07
	Figure 9	1.51	2.43



(a) (b) (c)

Figure 4. An example of the segmentation result: (a)hazy image, (b)associated pixonal imageand (c)final segmentation result.

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

Figure 5. Outputs of the proposed approach stages: (a)hazy image, (b)texture image, (c)smooth separated image, (d)dark channel and (e) proposed result.

(a) (b) (c)

Figure 6. Example 1 for subjective performance comparison of the proposed method with the DCP method in haze removing: (a)hazy image, (b)result of the proposed method and (c)result of the proposed method.

(a) (b) (c)

Figure 7. Example 2 for subjective performance comparison of the proposed method with the DCP method in haze removing: (a)hazy image, (b)result of the proposed method and (c)result of the proposed method.

(a) (b) (c)

Figure 8. Example 3 for subjective performance comparison of the proposed method with the DCP method in haze removing: (a)hazy image, (b)result of the proposed method and (c)result of the proposed method.

(a) (b) (c)

Figure 9. Example 4 for subjective performance comparison of the proposed method with the DCP method in haze removing: (a)hazy image, (b)result of the proposed method and (c)result of the proposed method.

5. CONCLUSIONS

This paper proposed a technique to fortify the DCP in enhancing hazy images. This technique employs different approaches for enhancing smooth and non-smooth areas of a hazy image. Thus, the image is initially segmented into smooth and non-smooth regions. Then, the smooth regions are enhanced using the Gamma correction approach, and the non-smooth regions are enhanced using the DCP methods. Depending to the haze severity, the DCP method might be re-applied to the non-smooth region for a better enhancement result. The subjective and objective comparison results provided in this paper showed that the proposed technique is superior to the DCP and the other existing DCP based methods in enhancing hazy images.

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چکیده

در این مقاله یک الگوریتم بهسازی برای رفع مه از تصاویر با استفاده از کانال تاریک پیشنهاد شده است. کانال تاریک یکی از روش‌های موثر برای رفع مه از تصویر است. کانال تاریک، تصویری هم‌اندازه‌ی تصویر دارای مه است که برای به دست آوردن آن، تصاویر رنگی RGB را به قسمت‌هایی تقسیم کرده و در هر قسمت مینیمم هر سه کانال R، G و B به صورت جداگانه محاسبه و دوباره از این سه مقدار مینیمم گرفته می‌شود و این مقدار جایگزین کل آن قسمت می‌شود. برای رفع مه از تصاویر با استفاده از کانال تاریک، یافتن تابع انتقال مه ضروری است و برای این تابع، نور محیط باید تخمین زده شود. با داشتن این دو عامل، می‌توان تصاویر بدون مه را بازیابی کرد. روش‌های مبتنی بر کانال تاریک در مورد تمامی تصاویر به خصوص برای نواحی هموار نتایج مطلوبی ندارند. در این مقاله با تقسیم بندی تصویر، نواحی هموار و غیرهموار از هم جدا می‌شوند، برای رفع مه از نواحی هموار از روش اصلاح گاما استفاده می‌شود تا وضوح این نواحی بالا رود. در نهایت برای نواحی غیر هموار با توجه به میزان مه آنها، از روش کانال تاریک استفاده می‌شود. از معیارهای کمی و کیفی برای نشان دادن برتری روش پیشنهادی نسبت به کانال تاریک استفاده شده است.

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