Single Image Dehazing based on Dark Channel Prior with Different Atmospheric Light

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Abstract: Single image dehazing based on dark channel prior could recover a high-quality haze-free image from non-sky image. However, it does not perform well in bright region such as sky region. This paper proposes a novel method for single image dehazing, which jointly considers the atmospheric lights of sky regions and land surface. In this proposal, we divide the image with sky regions into bright image (such as sky region and artificial light) and dark image (such as natural outdoor scenery and buildings) according to the image saturation, the intensity of pixels and Rayleigh scattering theory. In the recovery processing, bright image and dark image can be recovered separately with different parameters of atmospheric light. The experimental results show that the proposed scheme can obtain a high-quality haze-free image in the images which cover the sky.

1 INTRODUCTION

Computer vision system has been widely used into outdoor scene such as the urban traffic, video surveillance, remote sensing, navigation, target identification, etc. But cameras do not perform well in bad weather, especially in haze, fog, smoke. The turbid medium (e.g., particles, aerosol and water droplets) in the atmosphere can lead to atmospheric absorption and scattering. The irradiance received by the camera from the scene is attenuated, and then the output of camera is degraded seriously. Haze and fog restrict the function of outdoor system. Thus, single image dehazing is a channelling issue for image processing.

In the range of visible light, atmospheric scattering plays an important role in image degrading. The longer the distance from scene point to camera is, the greater the effect of atmospheric scattering is. The reasons of image degrading are listed as following: 1) Because of atmospheric scattering, the irradiance of scene is attenuated gradually along the line of sight. 2) The airlight - ambient light reflected into the line of sight by atmospheric particles (He et al., 2009)-is blended into the camera.

Due to the uncertainty of weather itself, single image dehazing has always been a challenging task. Recently, many single image haze removal algorithms have been proposed. Oakley et al. assumed that atmospheric light of whole image is constant and the mean and deviation of local pixels have a proportional relationship. Oakley proposed a statistical model to revise image contrast by optimizing the global cast function (Oakley et al., 2007). Tan et al. assumed that atmospheric light of whole image is constant and construct cast function of edge strength using Markov Random Field (MRF) model (Tan et al., 2008). His method just maximizes the local contrast and does not conform to physical model. Fattal et al. assumed that atmospheric light of whole image is constant and the albedo of the scene and the medium transmission are locally uncorrelated (Fattal et al., 2008). Meng et al. assumed that medium transmission derive an inherent boundary constraint on the scene transmission (Meng et al., 2013). The final transmission is calculated through iterative optimization. He et al. proposed dark channel prior for single image dehazing (He et al., 2009). He found that, in most of the local regions which do not cover the sky, some pixels very often have very low intensity in at least one color channel. But his approach is invalid when the scene object is inherently similar to the airlight. In this paper, we propose an improved method for images which cover the sky.

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2 SINGLE IMAGE DEHZING BASED ON DARK CHANNEL PRIOR

The model widely used in computer vision and computer graphics to describe the formation of a hazy image is(Tan et al., 2008; Fattal et al., 2008; Narasimhan et al., 2000; Narasimhan et al., 2002):

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

where ***I*** is the observed image, ***J*** is the scene radiance, ***t*** is the medium transmission and ***A*** is the global atmospheric light. ***I***, ***J*** and ***t*** are three-dimensional matrix function and ***A*** is a constant scalar. The goal is to get ***J*** from ***I*** in the premise that ***A*** and ***t*** are unknown.

Dark channel prior considers that in most of the non-sky patches at least one color channel has some pixels whose intensity are very low and close to zero (He et al., 2009). The dark channel J^{dark} is calculated by

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

where $\boldsymbol{J^c}$is a channel of surface shading, and $\boldsymbol{\Omega(\mathbf{x})}$ is a local patch centered at ***x***.

He et al. randomly pick out 5,000 images and manually cut out the sky regions. The intensity of all the 5,000 dark channel show that about 75 percent of the pixels in the dark channel have zero values, and the intensity of 90 percent of the pixels is below 25(He et al., 2009). According to the statistic the dark channel is given by.

$$\mathrm{J^{dark}(x)} \to 0 \qquad (3)$$

Putting (3) into (1), we can simplified the formula

$$\mathrm{I^{dark}(x) = A(1 - \tilde{t}(x))} \qquad (4)$$

when pixels at infinite distance, the medium transmission $\tilde{\mathbf{t}}$ tends to be zero .The intensity of the pixels at infinite distance could be regard as the global atmospheric light:

$$\mathrm{I^{dark}_{inf} = A} \qquad (5)$$

If the regions of infinite distance do not exist in the image, He et al. select the regions in which the concentration of mist is highest. In that areas ***t*** is small, and the approximation of ***A*** could be obtained. He picks the top 0.1 percent brightest pixels in the dark channel. Among these pixels, the pixels with highest intensity in the input image I are selected as the atmospheric light (He et al., 2009).

Figure 1: Haze removal with a larger atmospheric light. Left: Input hazy image. Right: Recovered haze free image.

The atmospheric light ***A*** is computed from formula (5). If the atmospheric light ***A*** is known, medium transmission could be got from formula (4):

$$\mathrm{\tilde{t} = 1 - \frac{I^{dark}}{A}} \qquad (6)$$

With the atmospheric light and the transmission map, the scene radiance could be got according to formula (1). However, the scene scattering term J(x)t(x) may be close to zero when the medium transmission t(x)is tend to zero. Therefore, He restricts the medium transmission t(x) by a lower bound t0=0.1 (He et al., 2009). The final scene radiance J(x) is recovered by

$$\mathrm{J(x) = \frac{I(x) - A}{\max(t(x), t_0)} + A} \qquad (7)$$

For reducing the complexity and reducing the halo artifact, He et al. applied guided image filter (He et al., 2013) to refine the medium transmission ***t(x).*** But, for sky regions, the method cannot perform very well. We presented a method to solve the problem

3 OUR PROPOSED METHOD

Dark channel prior is a simple but effective image prior. But it may be invalid when the scene containing sky. In the image containing sky the atmospheric light used to recover hazy image is larger than actual atmospheric light. Thus, the recovered image is darker than actual scene surface and color deviation exists in sky regions (see in Figure 1 right).

3.1 Different Atmospheric Light

We believe that the atmospheric lights of sky regions and land surface are different. The light of sky is come from the sun, but the light of land

Figure 2: Haze removal using different atmospheric light. Left: Input hazy image. Atmospheric light of sky region is 223. Atmospheric light of land surface is 162. Middle: Recovered by atmospheric light A=223. Right: Recovered by atmospheric light A=162.

surface is come from sky. The light is attenuated in the atmospheric medium. Therefore, the atmospheric light of sky is larger than land surface. Previous algorithm based on the atmospheric lights of sky and land surface are same. This is the reason why dark channel prior just perform well in non-sky images. In He's method (He et al., 2009), the atmospheric light is selected in sky region because the intensity of pixels in sky regions is larger than land surface. Thus, the atmospheric light of land surface is larger than actual light. According to formula (7), the land surface region in recovered haze free image is darker than actual scene and the sky region has a perfect result (see Figure 2 Middle). If we choose the atmospheric light of land surface as the atmospheric light of whole image, the sky region in recovered haze free image is brighter than actual scene and the land surface region perform well (see Figure 2 Right).From the comparison we confirm the conclusion that the atmospheric lights of sky and land surface are different.

3.2 Divide the Input Image

Lord Rayleigh proposed the theory of scattering in 1871. In the theory, when the size of particles in medium is same as molecule the intensity of scattering is inversely proportional to the fourth power of wavelength. The wavelength of blue and violet light is the shortest and the wavelength of red light is the longest in the solar spectrum. Otherwise, blue light has the largest power in short wave spectrum. Thus, sky is blue. The intensity of blue channel is largest and red channel is least in the sky regions of images.

Through a large number of experiments, we conclude three factors to distinguish the sky regions：

1) The intensity of three channels is almost same and the saturation is very small in sky regions. On the contrary, colorful scene has a larger saturation. In sky regions the intensity of blue channel is slightly higher and red channel is slightly lower. Therefore, the saturation of sky is close to zero. Through a lot of experiments, we find that the saturation of sky regions is below to 0.09. The saturation is expressed as:

$$S = \frac{\max_{c\in\{R,G,B\}} X^c - \min_{c\in\{R,G,B\}} X^c}{\max_{c\in\{R,G,B\}} X^c} \tag{8}$$

2) The intensity of pixels in sky regions is larger than land surface regions if there is not artificial light. Through experimental observation we find that the intensity of sky regions is above 200 in sunny day and above 160 in cloudy day.

3) According to Rayleigh scattering theory, the intensity of blue channel is largest and red channel is least in sky regions. In RGB channels, ***R<G<B***.

<u>Overview of dividing the Hazy image ***I(x)***:</u>

Input: Hazy image ***I(x)***

(1). Limiting condition c_1: c_1 is a matrix which size is same as saturation ***S***.

if (***S*** > 0.09) c_1 =1; **else** c_1 =0

(2). Limiting condition c_2:
if (maximum intensity of pixel>200) c_2=1
else c_2=0

(3). Limiting condition c_3:
if (***R<G<B***) c_3=1 **else** c_3=0

Figure 3: Image segmentation. Left: Input image. Middle: Sky region. Right: Land surface scene region.

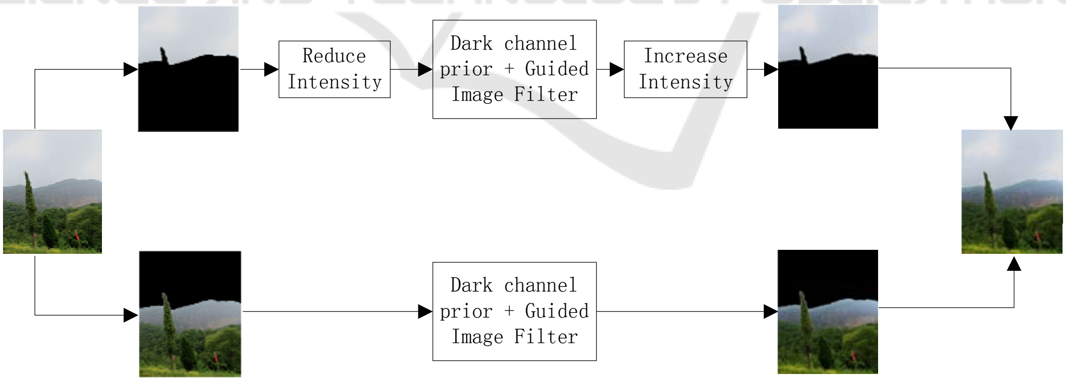

Figure 4: Algorithmic flow.

(4). $c=c_1\&c_2\&c_3$. If c=1, corresponding regions of input image is sky.
Output: sky region $I_{sky}(x)$, land surface region $I_{land}(x)$
In Figure 3, we show the results of segmentation using the three constraints.

3.3 Algorithmic Flow

This paper mainly focuses on the effect of atmospheric light and draws the conclusion that the atmospheric light of sky and land surface is different. The algorithmic flow is shown as Figure 4.

Since the different atmospheric light of sky and land surface, we divide input image into sky image

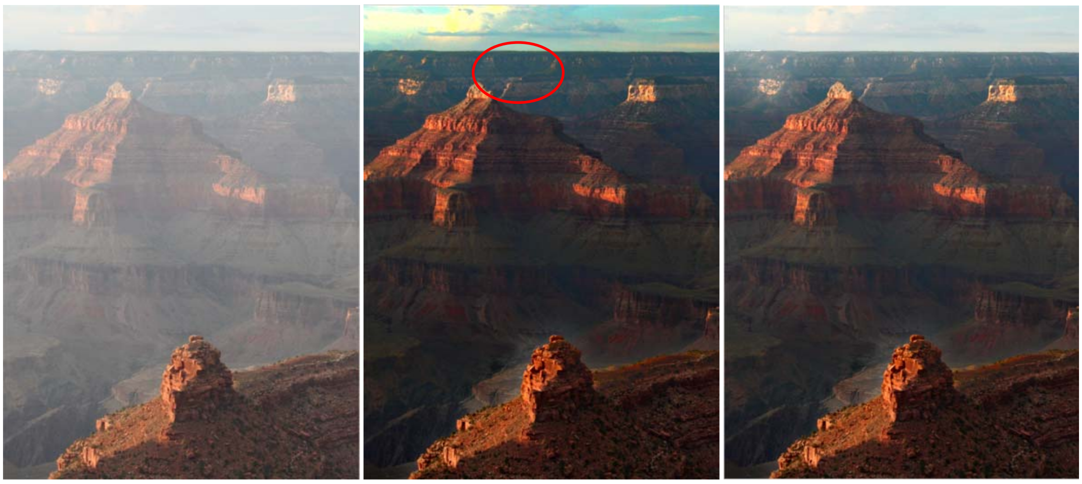

Figure 5: Comparison with He’s work. Left: Input image. Middle: He’s result. Right: Our result.

Figure 6: Comparison with He’s work. Left: Input image. Middle: He’s result. Right: Our result.

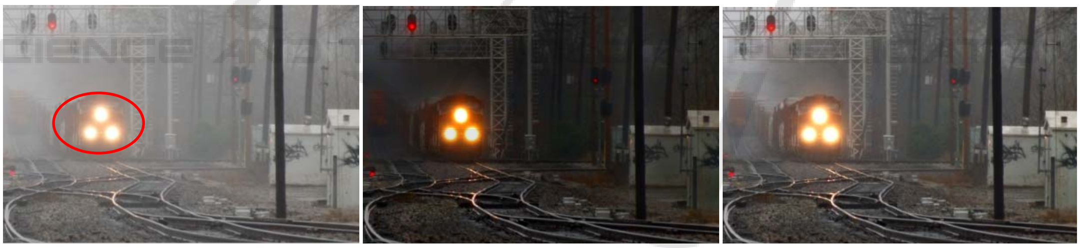

Figure 7: Comparison with He’s work. Left: Input image. Middle: He’s result. Right: Our result.

Figure 8: Comparison with other’s work. Input image. Fattal’s result. Meng’s result. He’s result. Our result.

and land scene image firstly. Dark channel prior could be directly used in land scene image. For sky image we reduce the intensity of sky by minus a constant value B. Recovered sky image plus B is the haze free sky image. Finally the integral haze free image could be got by stitching sky region and land scene region.

When the value of B is too large, the intensity of recovered sky regions may exceed 255 resulting in loss of information. When the value of B is too small, variation range of recovered pixels is too small lead to low contrast. Through a large number of experiments, it is appropriate when B is 100.

4 EXPERIMENTAL RESULTS

In Figure 5, Figure 6 and Figure 7 we compare our result with He's result. In Figure 5 Middle, the intensity of scene is darker than actual scene (e g: the red elliptical box) and color distortion occurs in sky patches. In Figure 6 Middle, the reflected light of water surface (see in the red elliptical box) is mistaken for haze and the distant scene is darker than actual scene. Artificial light (see in the red elliptical box) is exist in Figure 7 Left, and is mistaken for atmospheric light in Figure 7 Middle. Therefore, the color of whole image is darker than the actual color. Artificial light which atmospheric light is larger than land surface is same as sky.

In Figure 8, Fattal can't achieve a proper result. The overall recovered image is darker than real reflection image. In Meng's result sky regions appear color distortion, and there is a perfect recovery in land surface regions. Our results keep the actual color of sky and have the state-of-the-art contrast.

5 CONCLUSIONS

In this paper, we propose a method to solve the defect of dark channel prior-dark channel prior does not perform well in sky-images. Through the above discussion, our method has the state-of-the-art result for images which covered sky. But, our method may not work well for some particular images (e. g., images containing snow). The reason is that we need to divide the input image into sky region and land surface scene. Since the atmospheric light used in these two regions is different and the edge of segmented image is not accurate, the edge between them become more conspicuous, or may be brighter than sky region. We intend to solve the problem using image matting (Chuang et al., 2001; Levin et al., 2006) in future research.

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