VISIBILITY RESTORATION FROM SINGLE IMAGE BASED OPTICAL MODEL

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Abstract: In this paper, we propose a segmentation based method to estimate the haze-free image by the optical model. In this work, we estimate the atmospheric light by color barycenter hexagon (CBH) model and use the watershed to segment the image to calculate transmission map by dark pixels with single image. Firstly, non-color region is segmented by CBH model and calculate the atmospheric light. Then, use the watershed with *rang* component of CBH model to segment the color image into several sub-regions, and estimate the transmission map. Finally, use the optical model with the parameters to restore the haze-free image. The experimental results show that our method is more effective and able to get better results than other compared single image based methods.

1 INTRODUCTION

Image taken in the outdoors scenes usually influenced by many nature elements, such as, haze, smoke, fog, rain, snow and other atmosphere factors. Among of them, the atmosphere quality, haze is the most common problem in our daily life.So the haze removal problem needs be studied and obtain the more clear image for keeping the image quality in practical application.

For solving this problem, one kinds of approach is multi-image which captured in same scene with different haze level (Narasimhan and Nayar, 2000) (Narasimhan and Nayar, 2002) (Narasimhan and Nayar, 2003). These methods are use the multi-image to estimate the depth information. However, if the condition difference is little or hard to obtain the several images, the results will not accuracy. But, in many practical conditions, it's hardly to obtain the multi-image in same scene, especially the real-time application. So this condition limits the development and the practical application. Considering this short come, more and more researchers aim to do the research in single image for solving this. However, to obtain the depth information from single image is very difficult.

Short recently, some single image based haze removal methods have been developed (Fattal, 2008) (Tan, 2008) (Kratz and Nishino, 2009) (He et al., 2009). For single image, the depth information can't be calculated directly, so the estimation based methods are used. To solve this, the main framework is the optical model which widely be used. Fattal (Fattal, 2008) uses the Independent Component Analysis (ICA) to estimate the transmission map, but it hardly to obtain ideal results in heavy hazy condition. Also, if the ICA assumption not correctly enough, it will get wrong result. Tan (Tan, 2008) calculates the maximization of local contrast to enhance the image, and use Markov Random Field (MRF) for haze removing. But this method didn't consider the atmospheric light, so usually it leads to over-enhanced of some regions, specially the sky region. By analyzing many haze-free images, He *et al*. (He et al., 2009)propose a dark channel prior. The priors show that the haze-free image is close to black, and for hazy image become to bright. So its can be used to estimate the transmission map and the atmospheric light. However, for local bright or multi-light source it hard to obtain ideal results.

Considering the advantage and disadvantage of existing single image based methods, this paper proposed estimate the parameters by segmentation in CBH component.

The remainder of this paper as follows: In Section 2, the optical model is be introduced at first. Then, atmospheric light and transmission estimation are described. The compression and discussion of experi-

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mental results are shown in In Section 3. Finally, we conclude the advantage of proposed method and the future works.

2 HAZE REMOVAL ALGORITHM

Nowadays, the image optical (degradation) model is mostly be used in single image based haze removal methods (Fattal, 2008) (Tan, 2008) (He et al., 2009):

$$Y(x) = I(x)e^{-\beta d(x)} + A(1 - e^{-\beta d(x)}), \qquad (1)$$

where $Y(x)$ is the hazy image, $I(x)$ is the haze-free image; $e^{-\beta d(x)}$ is the atmosphere attenuation term, β is the coefficient and $d(x)$ is the distance from object to imaging plan (here call as the depth); A is the atmosphere light, and x is the position of pixel. Observing this model and the atmospheric scattering theory, the first term in the right hand is the diffuse reflectance of object and second term is the the diffuse reflectance of depth. For describe the model more simply, the $e^{-\beta d(x)}$ can use $T(x)$ to instead. So the Eq. (1) can be rewritten as:

$$Y(x) = I(x)T(x) + A[1 - T(x)], \qquad (2)$$

where $T(x)$ is the transmission map and have same feature with depth map. To estimate the haze-free image $I(x)$, only need get the atmosphere A and transmission map $T(x)$. However, single image haze removal problem is an *ill*-posed problem so it needs use some methods to change it to *well*-posed problem. Because of the parameters are unknown and cannot to estimate the original haze-free image by optical model exactly.

For estimating the A and $T(x)$, the first step is estimate the A and then use it to estimate the transmission $T(x)$. Recently, He *et al*. (He et al., 2009) proposed a new approach by observing the darkest value of R, G, and B of every pixel and defined it as dark channel.

$$I_{\min}(x) = \min[R(x), G(x), B(x)], \qquad (3)$$

And then get the statistical by dark values ($I_{min}(x)$) of many hazy images to get the prior which the dark channel can be defined as the transmission map (reflect the depth information) to estimate the haze-free image. He's method is new and the dark channel is novel, this prior is effective but in sometimes, the estimation of A and $T(x)$ is not accuracy enough. So in this paper, we use the dark prior with optical model and improve the parameters selection.

2.1 Atmosphere Light A Estimation

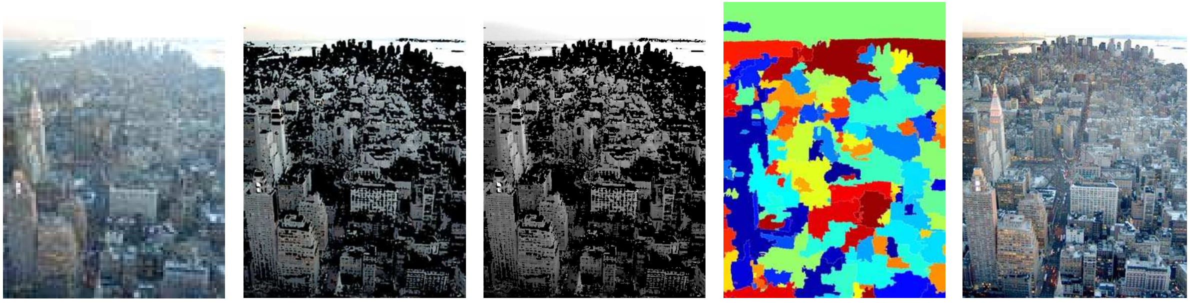
In some existing works, the atmosphere light A is estimate from the hazy image directly, but it usually not correct. In He's method (He et al., 2009), the author use the dark channel as Eq. 3 defined to estimate the position of A and calculate it from hazy image with same pixel. However, in some situations the local white influence it strongly, because the atmosphere light candidate should lager than white object. In He's method, by the some objects influence (such as the tree), the sky region may become to several separate regions and small than white object, also maybe the light intensity is weaker than it too. In this situation, the atmosphere light A usually select the white object and influence the estimation.

So to overcome this problem, the first thing is obtaining the correct candidate region and then select the ideal values. Here we use the color barycenter hexagon (CBH) model (Zhang and Kamata, 2008) to calculate the gray region (not real gray, only the pixels which not reflect the color information) for obtaining the atmosphere. At first, use the CBH model to detect the color pixels and turn them into black [Fig. 1(b)], then use the Eq. 3 to calculate the dark pixels [Fig. 1(c)]. After this processing, calculate the 0.1% brighter pixels in the image and use the average value of these pixels in original image as the atmosphere light A. By this selection, the obtained value can overcome the multi-light source influence.

2.2 Atmospheric Veil Transmission $T(x)$ Estimation

Considering the different objects have different diffuse reflection ability, also deferent distance have different diffuse reflection, here assume these two reflection are same simply. As the dark prior of He's method, here we also use it to estimate the transmission map. Different with He's method, in current paper we segment the image at first and then calculate in every region respectively.

In He's method, the overlapped patches are used to calculate the dark pixel to estimate the transmission. In our research, the segmentation with patches are not the idea in many times, so the region segmentation based method is studied to solve this. Considering the hazy image usually captured in city and include many small details and edge. So the normal edge detection or region segmentation method hard to get idea segment ion result. So here the watershed segmentation which introduced by Beucher and Lantujoul (Beucher and Lantujoul, 1979) is used. However, usually this method only used for gray image and can't used for color image directly. So here we use the CBH model to convert the RGB image to get the *rang* image which can reflect the color and region information more clear than normal gray im-



(a) Hazy image (b) Non-color region (c) Dark pixel (d) Segmented image (e) Our result

Figure 1: Atmosphere light estimation

age. After this, use the watershed method to segment the image to get several region [Fig. 1(d)]. If the area of region lager than 200 pixels, segment it into $s = area/200$ sub-regions equally, otherwise ignore it. Then, calculate the local minimum of every region with $\min(R,G,B)$ to obtain the rough transmission map $T_r(x)$. For obtaining more accuracy transmission, the soft matting (Levin et al., 2006) as He described is used to optimal $T_r(x)$ to show more details transmission $T(x)$.

2.3 Recovering the Haze-free Image

With the atmospheric veil transmission $T(x)$ and the atmosphere light A, the haze-fee image can be calculated by Eq. 2. Considering in sometimes, the value of estimated $T(x)$ is close to zero, direct use it may let the recovered pixel become to infinite. So use the minimum transmission value T_0 to limit the lower bound same as He's method (He et al., 2009). Finally, the recovered haze-free image $I(x)$ can be calculated by following equation:

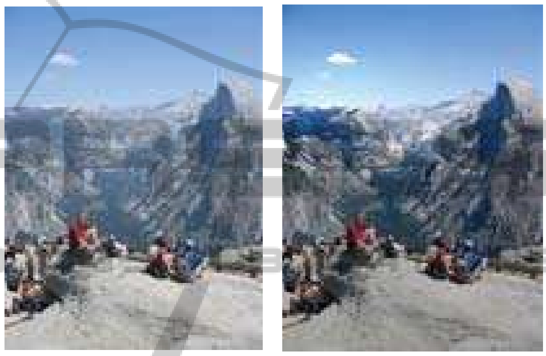
$$I(x) = \frac{Y(x) - A + AT(x)}{\max[T(x), T_0]}, \tag{4}$$

here T_0 set as 0.1. After the recovering, for obtaining more natural vision effect, the contract enhancement method (Zhang and Kamata, 2012) is used.

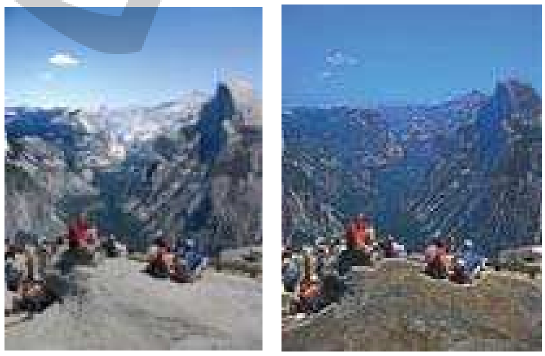
3 EXPERIMENTAL AND DISCUSSION

For comparing the results with other methods, some widely compared images are tested. In the experimental part, the previous works (Fattal, 2008) (Tan, 2008) (He et al., 2009) and histogram equalization (HE) are compared.

In Figs. 2 and 3, two natural images are compared with existing single image based methods. In



(a) Hazy image (b) HE



(c) Fattal's result (d) Tan's result

(e) He's result (f) Our result

Figure 2: Result comparison 1.

(a) Hazy image (b) HE (c) Fattal's result (d) Tan's result (e) He's result (f) Our result

Figure 3: Result comparison 2.

the 5 compared methods, HE makes the near region become darker and the far region brighter, but the haze removal effect is not good in far distance region. The effect of Fattal's methods (Fattal, 2008) is a little weak, only the near region have good effect. Tan's method (Tan, 2008) is the worst, too many details and the color information are missing because of the local contrast enhancement lost the global constraint. So the air region become to blue and the saturation of buildings become too deep. He's method (He et al., 2009) can get good effect, but the air region is not natural than HE, and the long distance become to dark. Compared with other methods, the proposed method makes the whole image become to clear, keeps the details and seems more natural.

4 CONCLUSIONS AND FUTURE WORKS

In this paper, a segment ion and CBH model based atmospheric light and transmission estimation method is proposed. The presented method use the color region segmentation to estimate transmission more accuracy and can restore more details for vision.

However, how to segment the image to get more accuracy transmission and without use the soft matting need be studied.

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