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Haze Scene Detection based on Hue, Saturation, and Dark Channel Distributions

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Abstract

Dehazing significantly improves image quality by restoring the loss of contrast and color saturation for images taken in the presence. However, when applied to images not taken according to the prior information, dehazing can cause unintended degradation of image quality. To avoid unintended degradations, we present a hazy scene detection algorithm using a single image based on the distributions of hue, saturation, and dark channel. Through a heuristic approach, we find out statistical characteristics of the distribution of hue, saturation, and dark channels in the hazy scene and make a detection model using them. The proposed method can precede the dehazing to prevent unintended degradation. The detection performance evaluated with a set of test images shows a high hit rate with a low false alarm ratio. Ultimately the proposed method can be used to control the effect of dehazing so that the dehazing can be applied to wide variety of images without unintended degradation of image quality.

Keywords: *Haze Detection, Haze Scene, Dehazing, Haze Analysis*

1. INTRODUCTION

Outdoor images captured in the presence of haze show loss of contrast and color saturation, due to turbid medium which absorbs and scatters lights. The image acquisition model in a hazy weather is established with transmission in each pixel position and color of the turbid medium, so called airlight. Dehazing derived from the acquisition model restores the scene radiance of an input image by removing the effect of haze [1-3]. For a hazy outdoor scene, dehazing provides significant improvement of image quality using prior information such as dark channel prior [3]. However, prior information is not applicable, when an input image is captured in a clear weather for example, dehazing can actually degrade image quality. To avoid such unintended degradations, checking the existence of haze in an input image can precede the restoration process. This paper proposes a hazy scene detection method which can distinguish clear scenes from hazy scenes image-wise. The proposed hazy scene detection can be applied to surveillance or automotive systems to turn on/off dehazing process for haze/clear scenes [4-6]. Quality of dehazed images is important not only for visual perception but also for the performance of image processing procedures that follow, such as feature extraction.

Pixel-wise haze detection has been studied for restoration of contrast in weather degraded images and for

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removal of haze in satellite images [7-9]. Multiple images of the same scene taken at different weather conditions or at different spectra are analyzed to detect the presence of haze. These approaches are not suitable for single image dehazing for which only one image of a scene is available. A method that detects haze with only a single image is proposed in [10]. A given image is semi-inversed, or dehazed with partial information, and compared with the given image. Regions with large hue shift are detected as the regions with haze. Hue shift in semi-inversed images can occur due to factors other than haze. The detection performance of the semi-inversion (SI) based algorithm can suffer from high false alarm ratio.

2. HAZE MODEL

The pixel values of a color image are given by

$$\mathbf{F}(i,j)=\left[\mathbf{F_r}(i,j),\mathbf{F_g}(i,j),\mathbf{F_b}(i,j)\right] \tag{1}$$

for $(i,j)\in\Omega$, where Ω is the set of pixel indices. The subscripts r,g, and b are used for the three color channels in the RGB color space. An image acquired in the presence of haze can be modeled by [2]

$$\mathbf{F_c}(i,j)=\mathbf{J_c}(i,j)\mathbf{T}(i,j)+\mathbf{A_c}\big(1-\mathbf{T}(i,j)\big) \tag{2}$$

for $(i,j)\in\Omega$, $c\in\{r,g,b\}$, where $\mathrm{J(i,j)}=\left[\mathrm{J_r(i,j)},\mathrm{J_g(i,j)},\mathrm{J_b(i,j)}\right]$ is the scene radiance, $\mathrm{A}=\left[\mathrm{A_r},\mathrm{A_g},\mathrm{A_b}\right]$ is the airlight and $\mathrm{T(i,j)}$ is the transmission. Dehazing is a process of restoring the scene radiance J from a given image F with the estimated airlight A and transmission T. For single image dehazing, both the transmission and airlight are estimated from a single given image. Once, the transmission and airlight are estimated, the scene radiance is restored by

$$\mathbf{J_c}(i,j)=\frac{\mathbf{F_c}(i,j)-\mathbf{A_c}}{\max(\mathbf{T}(i,j),\epsilon)}+\mathbf{A_c} \tag{3}$$

for $(i,j)\in\Omega$ and $\mathrm{c}\in\{\mathrm{r,g,b}\}$, where ϵ is a constant used to avoid numerical instability and to control the amount of dehazing effect.

Dehazing is based on the assumption that a given image is acquired according to the specific model given in (2), the restored scene radiance depends on the estimated transmission and airlight. When the transmission has small value, the restored scene radiance obtained by (3) can be significantly different from the acquired pixel value. For images that the transmission and airlight accurately describe the acquisition process, it means the restoration process can provide significant improvement of image quality. For images that the transmission or airlight fails to describe the acquisition process, it means significant degradation of image quality can occur. Our goal is to provide a model validation step in front of the restoration step for dehazing to be applied without causing unintended degradation for images without haze. In typical situations, outdoor scenes with haze include faraway sky, field, or mountain regions. In the presence of haze, pixels belong to hazy regions in outdoor scenes show low color saturation. We propose a hazy scene detection method based on this observation.

3. HAZE SCENE DETECTION

In many recent papers about dehazing, the efficiency of color information of hue, saturation, and value (HSV) is demonstrated [11-13]. Although human brain can easily characterize hazy outdoor scenes, detection or restoration of the haze from single image is usually ill posed and difficult. This heuristic inspires to use HSV color space which is more close to human perception. As an application for hazy scene detection, we also adapt the HSV color space.

The pixel values of a given image are transformed to the HSV color space [14], let $[\mathrm{F_h(i,j)},\mathrm{F_s(i,j)},\mathrm{F_v(i,j)}]$ be the HSV color for $(i,j)\in\Omega$. The subscript $\mathrm{h,s}$, and v are used for the hue, saturation, and value channels in the HSV color space, respectively. The set of pixel indices for which the hue values are between 0.5 and 0.625 are found by

$$\Omega_h = \{(i,j) \in \Omega \,|\, 0.5 \le \mathbf{F_h}(i,j) \le 0.625\} \tag{4}$$

The pixels in the set Ω_h include hazy regions in outdoor scene. As shown in Figure 1, the pixels affected by haze empirically take the hue in between 0.5 and 0.625. The pixels in Ω_h take the hue between the two black lines. This selection of the hazy regions reduces unnecessary search cost to alert haze.

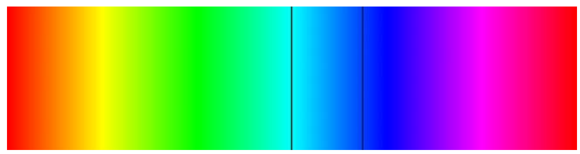

Figure 1. An example of the colors depending on hue. From left to right, hue linearly changes from 0 to 1.

We analyze the saturation and the depth information of the pixels only in the selected hazy region Ω_h. The depth information between the camera and objects is estimated using the so-called dark channel prior [3], which is based on the observation that the intensity of the dark channel is a rough approximation of the thickness of the haze. The dark channel of the normalized haze is obtained by

$$\mathrm{D(i,j)} = \min_{c\in\{r,g,b\}} \min_{(p,q)\in W_d(i,j)} \frac{\mathbf{F_c}(p,q)}{\mathbf{A_c}}, \tag{5}$$

where $\mathrm{W_d(i,j)}$ is the $(2d+1)\times(2d+1)$ size window centered at (i,j). $\mathrm{A_c}$ is pre-calculated using the method in [3]. The probability density function (pdf) of the saturation, $p_s(x)$, and the pdf of the dark channel, $p_d(x)$, are estimated by the histograms for the pixels in Ω_h:

$$p_s(x) = \mathrm{prob}\left[\mathbf{F_s}(i,j) = x, \text{for } (i,j) \in \Omega_h\right] \tag{6}$$

$$p_d(x) = \mathrm{prob}\left[\mathbf{D}(i,j) = x, \text{for } (i,j) \in \Omega_h\right] \tag{7}$$

We measure the Bhattacharyya distances [16] between the distributions of a given image and the target distributions by

$$d_s = \sqrt{1 - \int_0^1 p_s(x) p_s^0(x) dx} \tag{8}$$

$$d_d = \sqrt{1 - \int_0^1 p_d(x) p_d^0(x) dx} \tag{9}$$

where $p_s^0(x)$ and $p_d^0(x)$ are target distributions of the saturation and dark channel, respectively. Given an outdoor image, followings are key information about the hazy regions.

1. Dark channel values of the hazy regions are high [3].
2. Saturation values of the hazy regions are low [12, 13, 15].

Based on the above information, simple stochastic distribution for hazy images is designed. We choose the target distribution of the saturation, $p_s^0(x)$, to be uniform in $\left[0, \frac{1}{3}\right]$ which represents the second information and the target distribution of the dark channel, $p_d^0(x)$, to be uniform in $[\frac{2}{3}D_{max}, D_{max}]$ which represents the first information, where D_{max} is the maximum value of the dark channel. Because the distance information obtained from the dark channel depends on the image content, D_{max} is used instead of one. For example, if the entire image is filled with the fields at the similar distances, the dark channel values may not have values near one but the image still can be degraded by haze. The value for D_{max} is calculated from a given image after removing the top two percent of dark channel values in order to remove the effect of outliers. The Bhattacharyya distance measures similarity between two distributions. Two distances are small when pixels in Ω_h show low saturation and high dark channel values. A given image is classified as a scene with haze if

$$d_s d_d < \theta \tag{10}$$

where the threshold parameter θ is determined through a pilot experiment.

4. EXPERIMENTS

A set of test images consists of 77 images with haze and 61 images without haze is prepared. The images are labeled as with haze and without haze by manual inspection. The parameter θ of the proposed algorithm in (10) is determined through a pilot experiment performed with this test set. The parameter θ is set to 0.996.

For a performance comparison test, images in the database in [17] are used. 150 Images with haze and 150 images without haze are selected and labeled by manual inspection. The selected images are mostly of outdoor scenes. Images in the database are classified as airplane, cow, sheep, bench, bicycle, bird, building, car, chimney, cloud, door, flower, leaves, country-scene, urban-scene, tree, sign, etc. It is not reasonable to assume that all the images are acquired according to the haze model in (2), and to expect for dehazing to improve image quality of all the images. A model validation process should precede the restoration process.

The proposed algorithm is applied with the parameter θ determined through the pilot test. For comparison, the hazy scene detection based on the SI approach in [10] is implemented. The SI based algorithm detects regions with haze pixel-wise. In order to classify a given image as the one with or without haze, we modify the algorithm such that when 1/4, 1/8, or 1/16 of total number of pixels are detected as pixels with haze, the given image is classified as the one with haze. The SI based algorithms operated with 1/4, 1/8, or 1/16 of pixels to make a decision are denoted as SI(1/4), SI(1/8), and SI(1/16), respectively.

5. RESULTS

Table 1 shows the results of the hazy scene detection performance comparison test. The SI based algorithm provides a high hit rate when it declares a given image as with haze when even a small portion of pixels are with haze.

Table 1. Hazy scene detection performance comparison with a set of images from MSR Cambridge database

Method	Hit rate	False alarm
SI(1/4)	0.63	0.53
SI(1/8)	0.83	0.65
SI(1/16)	0.93	0.86
Proposed	0.79	0.32

The algorithm SI(1/4), SI(1/8), and SI(1/16) report increasing hit rates of 0.63, 0.83, and 0.93, respectively. However, the false alarm ratios also increase significantly if it declares the image as with haze when smaller portions of pixels are with haze. The false alarm ratios of SI(1/4), SI(1/8), and SI(1/16) are 0.53, 0.65, and 0.86, respectively. The SI based algorithms cannot provide higher hit rates without increasing the false alarm ratios. On comparison, the proposed algorithm provides the hit rate of 0.79 and the false alarm rate of 0.32.

Figure 2 example of unintended degradation by dehazing. Strong enhancement effects of dehazing on haze free images can degrade image quality significantly. All of SI(1/4), SI(1/8), and SI(1/16) find the image in Figure 2(a) as a hazy image. Dehazing degrades the image quality significantly as shown in Figure 2(b). The proposed method finds the image as a clear image. This example shows false alarm is important for hazy scene detection.

(a) *(b)*

Figure 2. An example of haze free image (a), and its dehazed image (b).

6. CONCLUSION

We propose a hazy scene detection method which checks whether a given scene is hazy or not, which is distinct from pixel-wise detection method of haze. The characteristics of the image regions with haze can be expressed in terms of hue, saturation and dark channel. The proposed hazy scene detection method using single image based on the distributions of hue, saturation and dark channel provides better performance with a high hit rate and a low false alarm ratio, than the hazy scene detection based on area of hazy regions calculated by a pixel-wise detection method of haze. The proposed method can be used to control the effect of dehazing so that the dehazing can be applied to wide variety of images without unintended degradation of image quality. Especially, the proposed method can be applied to surveillance or automotive systems to turn on/off dehazing process for a set of haze/clear scenes and also can be used in image capturing devices such as digital cameras and camcorders, and also in image display devices such as digital televisions to enhance image quality.

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