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Single image haze removal based on haze physical characteristics and adaptive sky region detection

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ABSTRACT

Outdoor images are often degraded by haze and other inclement weather conditions, which affect both consumer photographs and computer vision applications severely. Therefore, researchers have proposed plenty of restoration approaches to deal with this problem. However, it is hard to tackle the color distortion problem in restored images with ignoring the differences between fog and haze. Meanwhile, the atmospheric light is also an important variable that influences the global illumination of images. In this paper, we analyze the physical meaning of atmospheric light first, and estimate atmospheric light by a novel method of obtaining the sky region in images, which is based on our newly proposed sky region prior. Then after exploring physical characteristics of fog and haze, we explain why images taken in haze appear yellowish, and eliminate this phenomenon by our adaptive channel equalization method. Quantitative comparisons with seven state-of-art algorithms on a variety of real-world haze images demonstrate that our algorithm can remove haze effectively and keep color fidelity better.

1. Introduction

Outdoor images are always degraded by haze and other inclement weather conditions. The irradiance at long-range scene point is attenuated by turbid medium in atmosphere. Meanwhile, the airlight, a kind of environmental illumination caused by scattering in atmosphere increasing with pathlength also lighten the brightness. Therefore, the degraded images have poor quality of color and contrast particularly in those positions far away from the camera.

Image de-weathering has become a significant pre-processing step in computer vision application, especially for those images taken under inclement weather conditions. Plenty of algorithms have been proposed to improve image visibility. Most are based on the atmospheric scattering model proposed by McCartney [1] and obtain haze-free images by inverting the degradation process. The atmospheric scattering model can be expressed as

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

where x is the spatial location. $I(x)$ is the observed intensity, which also denotes the intensity of pixel x in the image. $J(x)$ is the scene radiance, namely observed intensity in well-lit conditions. A is the illumination caused by atmospheric scattering, which can be considered as horizon radiance. $t(x)$ is the medium transmission which shows the proportion of scene radiance in the camera's field of view without being scattered, and can be expressed as Eq. (2):

$$t(x) = e^{-\beta d(x)} \tag{2}$$

where β is the scattering coefficient and $d(x)$ is the depth of scene point x.

Such a model can be separated into two sections. $J(x)t(x)$ is the attenuation section named direct transmission [2], which denotes the radiance that ultimately comes into the camera; $(1 - t(x))A$ is the environmental illumination section firstly named as airlight by Koschmieder [3]. It is caused by scattering and its major sources are direct sunlight and diffuse sky light.

In this model, atmospheric light, A, is an important parameter, which indicates the ambient light, and controls the total illumination of images. Incorrect value of A can make images dark or over exposed as shown in Fig. 1.

However, the early methods either estimate atmospheric light from the brightest pixel or some of the particular regions. While significant progress of atmospheric light estimation has been made in [4–6] recently, there are still some shortcomings, and those are what we aim to tackle in this paper.

There is another apparent but easily ignored fact – haze differs from other weather conditions to a large extent. The Encyclopedia Britannica defines fog as: "cloud of small water droplets near ground level and sufficiently dense to reduce horizontal visibility

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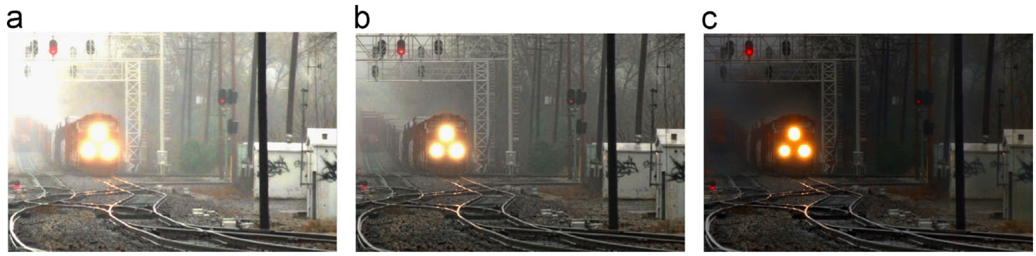

Fig. 1. Atmospheric light effect. (a) Result of the low atmospheric light (set as 112). (b) Result of proper one (set as 191). (c) Result of high one (set as 240).

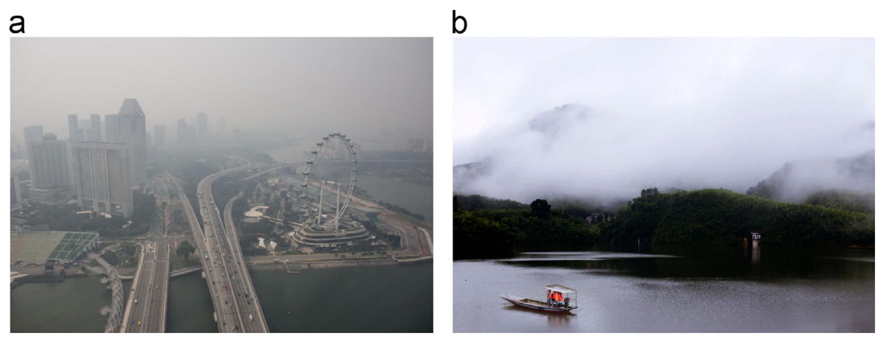

Fig. 2. Comparison of images taken in haze and fog. (a) Urban distant view in haze in Singapore. (b) Landscape in fog in China.

to less than 1000 m", and defines haze as "suspension in the atmosphere of dry particles of dust, salt, aerosols, or photochemical smog". It also indicates that haze "appears as a bluish or yellowish veil depending on whether the background is dark or light, respectively. With respect to these colours, haze can be discriminated from mist, which gives a grayish cast to the sky". The difference between mist and fog is only the degree of "invisibility". As can be observed in Fig. 2, images taken in haze and fog have significant differences. Intuitively, the concentration of fog is not uniform so that the image is not more blurry with the increase of depth. However, haze distributes uniformly, which makes the visibility decrease gradually. Moreover, the image taken in haze has lower brightness and contrast than that taken in fog and has a color distortion overall. Haze differs from fog in both definition and image manifestation, thus it is necessary to deal with those two kinds of images in different ways.

In this paper, we put forward a new prior, sky region prior. This sky region prior is a statistics prior based on thousands of images: for most outdoor images, it is common to find some parts of sky region. Based on this prior, we clip sky region from images and set it as the basis of atmospheric light estimation. Meanwhile, we analyze the differences between fog and haze. We find the components of haze and fog differ a lot which result in their different optical characteristics. It presents on images as biases of color and brightness ultimately. We eliminate color distortion by proposing an image adaptive channel equalization method. Our newly proposed method can overcome the shortcoming of not adapting to sufficient images dynamically, which exactly exists in gray world assumption. In the meantime, we also convert the images to a parameter improved HSI color space to adapt to the characteristics of haze and avoid over-saturation, which appears in [7]. After obtaining the coarse transmission map, we refine it by bilateral filter, a method can both smooth and preserve edge. Finally, we test the effectiveness of our algorithm through groups of experiments with existent state-of-art approaches.

2. Related works

In this section, we firstly describe the development of hazed removal. Then we also briefly introduce recent atmospheric light estimation methods, which serves as comparisons with our novel sky detection method.

2.1. Development of haze removal methods

On the whole, the early works often dehaze with more information than what one image can provide; Kopf et al. [8] remove haze by already existing georeferenced 3D models which give the depth of images; Narasimhan and Nayar [9] propose an approach which restores images on the basis of additional information provided interactively by users; Chen et al. [10] restore images through two or more images taken under different weather conditions; The approach of Schechner et al. [11] removes haze through two or more images taken with different degrees of polarization; Feng et al. [12] propose a method that obtains a pair of RGB image and near-infrared (NIR) image and then restores images by exploiting their dissimilarities.

Recently, researchers focus on the technique of dehazing with single image. Tan [13] restores images by maximizing the contrast. However, he does not take the degradation reason into consideration, thus there is always a color distortion in his results. Then most approaches obtain haze-free images by inverting the degradation process in terms of the atmospheric scattering model as demonstrated in Section 1. Fattal [14] derives the medium transmission by the assumption that surface shading and transmission function are locally statically uncorrelated. Tarel and Hautière regard the light increasing part as atmospheric veil and handle both color and gray images under their modified model. He et al. [7] propose an effective statistical prior named dark channel prior to remove haze: most non-sky patches in haze-free images contain some pixels which have very low intensities in at least one color channel. Gibson et al. [15] replace the soft matting in [7] with median filter to satisfy real-time demand and apply it to video