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Improved algorithm for image haze removal based on dark channel priority☆

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ABSTRACT

An improved algorithm is proposed for image haze removal based on dark channel priority to avoid the color distortion of haze removing about sky, white cloud or bright areas. The improved algorithm is mainly reflected in the following two aspects. One is the refined atmospheric transmittance of the hazy images with non-sky obtained using guided filter. The other is that the atmospheric transmittance of the hazy images with the sky, white cloud or the bright areas is estimated by a variety of classified statistics for haze-free outdoor images with non-sky or the haze-free outdoor images with sky. Compared with He algorithm, the weakness of atmospheric transmission of the hazy images with the sky, white cloud or the bright areas is remedied. Experimental results show that the improved algorithm is efficient to image haze removal.

1. Introduction

Outdoor images obtained in adverse weather (e.g., foggy or hazy) usually lose contrast and fidelity, resulting from the fact that light is absorbed and scattered by the turbid medium such as suspended particles and water droplets in the atmosphere during the process of propagation [1]. Most automatic systems for surveillance, navigation, aviation and intelligent vehicles, etc., work well when the input images have clear visibility. Therefore, improving the technique of image haze removal has received increasing attention in image understanding and computer vision fields during recent years.

So far, the image haze removal algorithm based on physical model has been demonstrated to be successful. The degradation model that is widely used in image dehazing algorithm is the hazy image model proposed by McCartney et al. [2] based on the atmospheric optics, and a few methods have been proposed. However, the image dehazing is a challenging problem because the hazy image is dependent on the unknown information. The problem is under-constrained when the input is only a single original fog image. Therefore, many image haze removal algorithms have been proposed based upon additional information. The success of these approaches lies in using a stronger priority or assumption. In literatures [3–5], a few methods for image dehazing have been proposed. For example, Fattal et al. [3] estimated the albedo of the scene and then inferred the medium atmospheric transmittance under the assumption that the atmospheric transmittance and surface shading are locally uncorrelated. Fattal algorithm was physically sound and could produce impressive results. However, Fattal algorithm cannot well handle dense hazy images and may be failed in the case that the assumption is broken. Tarel

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et al. [4] proposed a fast image haze removal algorithm using a median filter which used the atmosphere of dissipation function close to the maximum value and had the characteristics of local changing gently within certain feasible area. Since the median filter is not conformal and edge-preserving, it does not respect with the depth information of the scene. He et al. [5] first proposed a dark channel prior image haze removal algorithm that was based on the statistics of haze-free outdoor images with non-sky. Combining a haze image model and a soft matting interpolation algorithm [6], the literature [5] recovered a high-quality haze-free image. However, the algorithm in [5] had higher calculation complexity as the additional using of the soft matting algorithm. He [7] further proposed the guided image filter, which could be used to refine the atmospheric transmittance map. From the experimental results of [5] and [7], we can see that the algorithm in [5] had a slower convergence speed than the algorithm in [7]. Classical He algorithm (i.e. [7]) is simple and effective in most cases. Whereas, it cannot well handle the images include the sky, white cloud or the bright areas. A comprehensive survey of dark channel prior based could be referenced to [8]. Some improved algorithms [9–11] are proposed to overcome the weakness of the classical He algorithm. L. Kratz et al. [9] estimated a more accurate transmission by modeling the image with a factorial Markov Random Filed. Meng et al. [10] proposed an effective regularization image haze removal algorithm to restore the haze-free image by exploring the inherent boundary constraint. Tang et al. [11] combined four types of haze-relevant features to estimate the atmospheric transmittance. Xiao et al. [12] used guided joint bilateral filter for fast image dehazing. Although these results obtained by these improved algorithms seem visually compelling, their processing results are all low contrast or color distortion in the sky, white cloud or the bright areas. In addition, the atmospheric transmittance of the haze images with sky or non-sky in these improved methods is assumed to be constant, while the actual atmosphere transmittance should be a function relation to the dark channel prior values, which we will discuss in Section 3.

In this paper, an improved image haze removal algorithm is proposed based on dark channel priority. Firstly, the refined atmospheric transmittance of the hazy images with non-sky is estimated using guided filter. Secondly, the atmospheric transmittance of the sky, white cloud or the bright areas is obtained by a variety of classified statistics of the haze-free outdoor images with non-sky or the haze-free outdoor images with sky. Finally, the atmospheric transmittance of the hazy images including the sky and non-sky is estimated. Thus, our proposed improved algorithm can well handle the color distortions in the sky, white cloud or the bright areas and produce high-quality recovered results.

This paper is organized as follows. Section 2 describes the image haze removal algorithm based on dark channel priority, Section 3 proposes the improved algorithm, Section 4 presents experimental results, and Section 5 concludes this paper.

2. Dark channel priority

2.1. Atmospheric scattering model

The optical model is usually used in dealing with hazy images, particularly in computer vision and computer graphics. The model [2] widely used to describe the formation of a hazy image and haze-free image is as follows:

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

where $I(x)$ is RGB image collected in the hazy weather by outdoor visual system, $J(x)$ is the RGB haze-free image, A is the global atmospheric light, and $t(x)$ is the atmospheric transmittance. If we can get the image atmospheric transmittance $t(x)$ and the atmospheric light intensity A, under the circumstance the hazy images being known, we can restore the original haze-free images according to the Eq. (1).

2.2. Dark channel priority

The dark channel priority [5] is based upon the observation on haze-free outdoor images with non-sky, and some RGB color channels (at least one) have very low intensity at some pixels. In other words, the minimum intensity in such a patch should have a very low value, i.e.

$$J^{dark}(x) = \min_{c\in\{R,G,B\}} (\min_{x\in\Omega(x)} (J^c(c))) \approx 0 \tag{2}$$

where $J^c(c)$ represents a color channel of $J(c)$, $\Omega(x)$ denotes a local patch centered at x, and $J^{dark}(x)$ represents a dark channel of the $J(x)$. After taking the minimum operation among three RGB color channels in the local patch on the haze images by using Eq. (1), we obtain:

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

where A^c represents a color channel of the A. Thus, due to the Eq. (2), the following Eq. (4) can be obtained.

$$J^{dark}(x) = \min_{c\in\{R,G,B\}}\left(\min_{x\in\Omega(x)}\left(\frac{J^c(x)}{A^c}\right)\right) \approx 0 \tag{4}$$

The product $J(x)t(x)$ could be very close to zero when the atmospheric transmittance $t(x)$ is close to zero. After substituting Eq. (4) into Eq. (3), we can optionally keep a very small amount of haze for the distant objects by introducing a constant