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A multi-scale fusion scheme based on haze-relevant features for single image dehazing

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ABSTRACT

Outdoor images are often degraded by aerosols suspending in atmosphere in bad weather conditions like haze. To cope with this phenomenon, researchers have proposed many approaches and single image based techniques draw attention mostly. Recently, a fusion-based strategy achieves good results, which derives two enhanced images from single image and blends them to recover haze-free image. However, there are still some deficiencies in the fusion-input images and weight maps, which leads their restoration less natural. In this paper, we propose a multi-scale fusion scheme for single image dehazing. We first use an adaptive color normalization to eliminate a common phenomenon, color distortion, in haze condition. Then two enhanced images, including our newly presented local detail enhanced image, are derived to be blended. Thereafter, five haze-relevant features of dark channel, clarity, saliency, luminance and chromatic are investigated since those can serve as weight maps for fusion. Dark channel, clarity and saliency features are finally selected due to their expression abilities and less interconnection. The fusion is processed with a pyramid strategy layer-by-layer. The multi-scale blended images are combined in a bottom-up manner. At last quantitative experiments demonstrate that our approach is effectiveness and yields better results than other methods.

1. Introduction

Outdoor images often suffer from the problem of degradation since the scattering by atmosphere particles in some inclement weather conditions like haze. The color and details of distant scenes always fade away in these images, which both affect on image quality and related applications, such as outdoor monitoring and remote sensing. Therefore haze removal has become a significant pre-processing step in computer vision application.

Researchers have proposed many approaches for improving the visual manifestation. On the whole, the early works restore images with additional information, which includes already existing georeferenced models [1] and users' input parameters [2]. Nevertheless, when the information is inaccessible or inaccurate, for example, the geographic model has never been established or the user gives wrong inputs, these methods fail. Then some researchers propose multi-image based methods, which fall into three categories: different polarization degrees based [3] and [4], different weather conditions based [5] and [6] and RGB/Near-infrared images [7] and [8] based. However, these methods are not easy to be taken into practice since they require more than one ordinary camera.

Recently, researchers focus on single image dehazing, most of which are based on an atmospheric scattering model proposed by McCartney [9] in 1972, which can be expressed as:

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

where $I(x)$ is observed intensity, which is also the intensity of pixels in the image. $J(x)$ is the scene radiance, namely observed intensity in well-lit conditions. A is illumination caused by atmospheric scattering, which can be considered as horizon radiance. $t(x)$ is the medium transmission which shows the amount of scene radiance reaches into camera without being scattered, and can be expressed as:

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

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

Nevertheless, as single image dehazing is a solution of indeterminate equation, hypothesis or prior is required for exploring more information. Consequently, these methods fail when the hypothesis or prior is invalid. Noticing those failures, Ancuti and Ancuti [10] propose a fusion scheme. Though only one hazy image

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is required for the restoration process, two enhanced images of white balance and contrast enhancement are derived for fusion. The former better depicts the haze-free regions whereas the latter increases visible details of the hazy regions. Subsequently, they derive luminance, chromatic and saliency weight maps from the two images to be blended and obtain the final weight map by multiplying them together. The core of their scheme is a pyramid fusion, which employs Laplacian operator for those two enhanced images and Gaussian operator for their weight maps. It yields a good result, but still has some shortcomings. Firstly, the white balance image is obtained following the method of shade-of-gray, which is proposed by Finlayson and Trezzi [11], and can be deemed a derivative of gray-world method [12]. Such a method is based on the assumption that when the given image is with sufficient amount of color variations, the red, green and blue channel should average out to a common gray value. That assumption is error-prone because it cannot adapt to dynamic scenes, especially when the color of image tends to be monotonous. In a hazy image, color distortion caused by the atmospheric color is more common than other weather conditions, thus the mean value of color will shift and shade-of-gray method cannot give a satisfied result. Besides, their weight map strategy is also not appropriate enough.The chromatic map derived from saturation in HSI color space weights low intensity regions higher, in which the details are not discriminative. Therefore, there is no point for the chromatic map to serve as weight map.

In this paper, we propose a single image dehazing approach based on a multi-scale pyramid fusion scheme. As we aim at dehazing, the color distortion is what we need to eliminate firstly. According to the physical characteristic of haze, we adopt an adaptive solution proposed by Li [13], which exploring the atmospheric light information provided by the image itself. Then we derive two images of local detail enhancement and global contrast enhancement from single hazy image as input images for fusion. Considering haze affect differently on those two enhanced images, the weight maps can be regarded as a kind of haze-relevant feature that indicates such an influence. Five haze-relevant features are investigated in this paper, including dark channel, clarity, saliency, luminance and chromatic. The dark channel, clarity and saliency features are chosen as weight maps in this paper due to their high relativity to haze and less interconnection. The overview of our approach is depicted in Fig. 1. Quantitative experiments demonstrate that our approach achieves better results than 10 state-of-the-art methods including Ancuti and Ancuti's method.

2. Related works

In this section, we give a brief review of related works, and especially for the work of Ancuti and Ancuti [10] in Section 2.2.

2.1. Development of haze removal methods

Degraded image restoration has witnessed many a achievement in last decades. Although most of them are entitled with "dehazing" or "defogging", they are essentially equivalent because they do not distinguish them from both visual manifestation and physical characteristic. Therefore they are more like general image restoration than truly haze removal. The development of this issue can be deemed a three-step process of extra infor based, multiple images based and single image based approaches. As mentioned above, most of the early works improve images' quality by addition information. Kopf [1] obtain the depth of image, geography features and other GIS information from already existing georeferrenced digital models and apply it into image restoration. Narasimhan [2] deweathering by additional information provided by users interactively.

Narasimhan and Nayar [2] propose a chromatic model after investigating visual manifestations under different weather conditions and recover scene color in well-lit conditions. Schechner [3], Shwartz [4] obtain the depth of image through two or more images taken with different degrees of polarization. Chen [5] estimate depth of the image by exploiting a pair of images taken in sunny day and fog day. Schanul [7] and Feng [8] obtain a RGB image and an infrared image in the same time, which are used in restoring process.

In recent years, the research on this issue has been gear towards single image based restoration. Tan [14] firstly propose a single image defogging method, which separates the intensity of atmospheric light from its chroma, and then restores image with achromatic atmospheric light. Tan [15] restores image by maximizing the contrast. Fattal [16] estimates scene albedo first and derives medium transmission under the assumption that the surface shading and transmission function are locally uncorrelated. Tarel and Hautière [17] regard the intensity-raising part as a veil, and handle both color and gray images under their improved model. He [18] propose an effective statistical prior - dark channel prior for removing haze, which is stated as: in most non-sky patches of haze-free images, at least one color channel has very low intensity at some pixels. Then many researchers make some improvements on the basis of [18]. To satisfy the real-time demand, Gibson [19] replace the soft matting in [18] with median filter. Fang [20] use a graph-based image segmentation method to eliminate halo effect which is generated by minimum filter in [18]. Dong [21] decompose the observed haze image into a coarse image and a detail image using Gaussian–Laplacian pyramid, as the size of image is decreased, the computational complexity of calculating DCP can be also decreased. Tang [22] present a novel machine learning based approach. They firstly analyze the haze-relevant features, such as dark channel, local contrast, hue disparity and saturation. Based on those features, they use random forest to learn a regression model for haze removal. Zhu [23] separate image into sky region and non-sky region and deal with them in different ways, which avoid the over-handling in sky region. Meng [24] propose a boundary constraint to impose a geometric constraint on the range of transmission. Then the transmission map is refined by optimizing with a contextual regularization. Park [25] optimize local transmission function to solve the problems of low contrast and over-saturation. Sulami [26] focus on the atmospheric light vector, A. They derive a reduce formation model to refine atmospheric light estimation with a two-step strategy that calculates the magnitude and orientation of atmospheric light in sequence. Wang [27] present a new local brightness adaptive variational model using Wasserstein distance as a dispersion energy term to measure the statistical similarity between the original image and the enhanced image. Huang [28] notice that the hazy images also suffer from color distortion, thus they try to normalize the color using the gray world assumption. They extends it with a novel Laplacian-based visibility restoration approach to better alleviate the color cast problems [29]. Chen [30] propose an approach based on Bi-Histogram modification to estimate haze density in the transmission map. Zhu [31] propose another prior named Color Attenuation Prior for dehazing and employ a linear model for modeling the scene depth. Zhang [32] dehaze by a scene-adaptive segmentation, which separate the image into close view and distant view. Then an improved dark channel is employed to regularize the atmospheric veil and estimate atmospheric light value. Similarly, Liu [33] first separate the image into close view and distant view. Then they propose an opening dark channel model to estimate the transmission map. Bhattacharya [34] avoid using any prior and instead employ a stochastic iterative algorithm for haze removal. Berman [35] propose a new prior called non-local prior stating that colors of a haze-free image are well approximated by a

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