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Single image dehazing with a physical model and dark channel prior

Jin-Bao Wang [a], Ning He [a,*], Lu-Lu Zhang [a], Ke Lu [b]

[a] Beijing Key Laboratory of Information Service Engineering, College of Information Technology, Beijing Union University, Beijing 100101, China
[b] Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

We propose a single image dehazing method that is based on a physical model and the dark channel prior principle. The selection of an atmospheric light value is directly responsible for the color authenticity and contrast of the resulting image. Our choice of atmospheric light is based on a variogram, which slowly weakens areas in the image that do not conform to the dark channel prior. Additionally, we propose a fast transmission estimation algorithm to shorten the processing time. Along with a subjective evaluation, the image quality was also evaluated using three indicators: MSE, PSNR, and average gradient. Our experimental results show that the proposed method can obtain accurate dehazing results and improve the operational efficiency.

1. Introduction

The intensification of environmental pollution has seen levels of SO_2, NO_X, and particulate matter increase sharply in recent years. The first two are gaseous pollutants, but particulate matter is the most important factor in the appearance of haze. When combined with fog, the sky appears gray. The quality of a photograph taken in hazy weather is severely reduced because a large number of small particles refract and reflect the light before it reaches the camera lens. Therefore, the contrast of the photo is reduced and color images lose a lot of detail, especially in terms of the depth of objects. Thus, the information contained in these pictures is greatly reduced, as shown in Fig. 1(a) and (c). In practical applications such as military technology, traffic, forensics, meteorology, and astronomy, it is often necessary to extract image features from a collection of outdoor video sequences. Thus, the dehazing of images has become an urgent and practical research topic. The dehazed image is more visually pleasing, contains more information, and can be widely used in many fields. For example, dehazed images are an effective source of data in computer vision, as shown in Fig. 1(b) and (d). In image processing, image dehazing is used as a pre-processing method. For instance, Gibson et al. [7] investigated the dehazing effects on image and video coding for surveillance systems. Wang et al. [24–28] improved the accuracy of image relevance ranking and image or video annotation using dehazed images. Further, Gao et al. [4–6] used dehazed images for 3D object retrieval and recognition. Restoring the true image from the fog-impaired version has important academic and practical significance.

Early approaches to image dehazing used a physical model for haze removal. This mainly relies on additional depth information or multiple observations of the same scene. Kopf et al. [9] proposed a method to recover hazy images using a 3D model or scene depth information, which is directly accessible from digital terrain maps or Google Earth. This method has limited practical applications. Schechner et al. [18,20] noted that the light scattered by atmospheric particles is partially polarized. Using this, they proposed a quick method for removing haze by taking two images through a polarizer at different angles. However, this method does not conform to the real physical model. Narasimhan et al. [13–17] proposed a physics-based scattering model based on the binary scattering deduced from the RGB color space. The haze-free scene structure can be recovered from two or more weather images by determining the 3D structure of the hazy scene. However, they assume that the atmospheric scattering coefficient does not change with the wavelength of light. This assumption is only an approximation in foggy weather conditions. Therefore, we cannot produce good results by processing hazy regions in a similar way as areas of sky in the binary scattering model. By considering fog and haze as a kind of noise, hazy images can also be processed using the methods in [1,11]. However, the formation of fog and haze are varied, so the visual appearance of the dehazed images are not very accurate.

Significant progress has been made on single image dehazing in recent years. However, the increasingly detrimental effect of

* Corresponding author.
E-mail addresses: linkingring@163.com (J.-B. Wang), xxthening@buu.edu.cn (N. He), rainpgy@163.com (L.-L. Zhang), luk@ucas.ac.cn (K. Lu).

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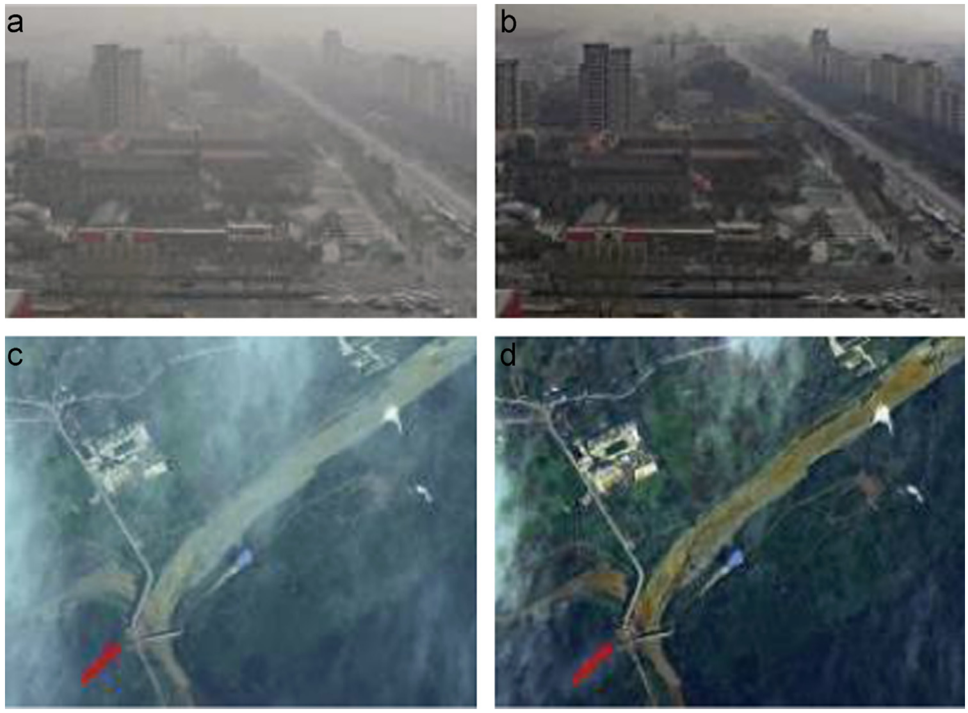

Fig. 1. Image dehazing results, (a) and (c): foggy images; (b) and (d): dehazed results given by our method.

haze, smoke, and fog means that less scene structure information can be used, so single image dehazing has become more challenging. Fattal et al. [2] proposed a mathematical model for image dehazing. This model describes the surface shading of the objects and the scene albedo. By assuming that the two functions are locally statistically uncorrelated, hazy images can be divided into regions of constant albedo. These can be used to infer the actual scene. The algorithm is based on local statistics and requires sufficient color information. A larger haze concentration means that the scene loses more energy. This gives the scene a gray appearance, and a relatively small local variance. So this method cannot effectively estimate the transmission coefficient. Therefore, only the local transmission coefficient can be estimated. When objects are far from the camera, there will be a certain degree of mist. Tan et al. [23] enhanced hazy images by maximizing their local contrast. Although this method was successful in regions with very dense haziness, the color of the haze-free image is often oversaturated. This phenomenon is caused by the haze concentration being overestimated in the process of contrast maximization, a result of using image enhancement technology instead of a physics-based method. Kratz et al. [10] proposed describing an image as a factorial Markov random field, in which the scene albedo and depth are two statistically independent latent layers. A canonical expectation maximization algorithm is implemented to factorize the image, recovering haze-free images with fine edge details, but sometimes the output images are over-enhanced. He et al. [8] proposed a dark channel prior algorithm. The dark channel prior is the result of an observation of outdoor haze-free images, in which most of the non-sky patches have at least one color channel containing low intensity pixels. Statistical results show that most of the outdoor pictures satisfy this requirement. Combined with soft matting, the dark channel prior method achieves outstanding results with hazy images and obtains the corresponding depth image. This is currently one of the most effective dehazing methods. The dark channel prior may be invalid when the scene object is inherently close to the airlight. Further, this method cannot process gray areas of the image very well and is somewhat time-consuming. Sun et al. [21,12,19,29] also obtained good results with algorithms based on the dark channel prior.

This article proposes a kind of atmospheric scattering model and dark channel prior principle based on the work of He [8] and others. First, we improve the transmission map, which reduces the processing time. Second, as the atmospheric light plays a very important role in the dehazing effect, we derive a new method to select this value. This method overcomes the deficiency of the dark channel prior, and reduces the influence of white objects or sky areas on the whole image. Finally, we obtain a clear image without fog.

2. Background

2.1. Physical model

Fattal et al. [2] studied the physical model of atmospheric scattering and optical reflectance imaging. In computer vision and computer graphics, the model widely used to describe the formation of a hazy image is

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

where $I(x)$ is the observed image, $J(x)$ is the scene radiance, A is the global atmospheric light, and $t(x)$ $(0 \le t(x) \le 1)$ is the scene transmission (which describes the portion of light that is not scattered and reaches the camera). The aim of haze removal is to recover $J(x)$, A, and $t(x)$ from $I(x)$.

This model explains the decline in image contrast produced by the haze. For a patch with a given uniform transmission $t(x) = t$,

$$\|\nabla I(x)\| = \|t\nabla J(x) + (1 - t)\nabla A\| = t\|\nabla J(x)\| < \|\nabla J(x)\|, \tag{2}$$

where ∇ is the gradient value of the image. Because $0 \le t(x) \le 1$, this formula shows that the average gradient value of the input image decreases as the haze increases, resulting in a blurred image.