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A Review of Traditional Dehazing Methods for Foggy Images

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Abstract: Photographs taken under foggy conditions are prone to low contrast, color deviation, and blurred local details, which are detrimental to advanced computer vision tasks such as image recognition, semantic segmentation, and image detection. Although deep learning techniques have made significant progress in image dehazing, the effectiveness and role of traditional image dehazing methods are still fundamental and have their unique advantages. Based on this, the principles and advantages of the existing advanced traditional methods are analyzed from image restoration and enhancement perspectives, and standard datasets are introduced. Finally, predictions for the future direction of the traditional image dehazing field are presented.

Keywords: Atmospheric scattering models; Contrast enhancement; Image dehazing; Image enhancement.

1. Introduction

Due to the combination of dust, water mist, and other tiny particles in the air, a foggy environment is formed with low outdoor visibility. Images taken under such conditions largely diminish the image's visual effect and adversely affect traffic monitoring, gate recognition, and fruit counting realistic scene applications. They could be more conducive to image recognition, semantic segmentation, image detection, and other computer vision tasks. Image dehazing reduces the impact of fog on an image as much as possible, and dehazing reduces a fogged image to a fog-free image. The removal of fog not only improves the image's visual effect but also significantly improves the performance of the computer vision task.

There are currently two main types of traditional processing methods for image dehazing: one is based on image restoration methods for image dehazing. The image restoration approach is mainly based on an atmospheric scattering model and performs dehazing processes. This method is more targeted and achieves natural results with little loss of information, but estimating the various parameters in the model is a tricky area of research. Another type of image-dehazing method is based on image enhancement. The image enhancement method removes as much image noise as possible, increases the image contrast, and improves the image's visual effect. Still, it may cause some loss of information for some of the information.

This paper summarizes and compares image dehazing in two traditional directions: image restoration and enhancement. It mainly summarizes and reviews the research results in these two directions, summarizes their dehazing principles and experimental results, gives a brief introduction to commonly used image-dehazing datasets, and finally gives a reasonable prediction of the future development direction in the field of image-dehazing.

2. Traditional image dehazing methods based on image restoration

The image restoration method is mainly based on the backpropagation formula of the atmospheric scattering model, the parameters such as atmospheric light value and transmittance map in the atmospheric scattering model are estimated based on a priori information, and the clear fog-free image is restored by substituting the backpropagation formula. In general, it has a certain dehazing effect on the image as a whole. Still, such methods are based on the model's parameter estimation and a priori information and tend to be more effective for special scenes with a relatively homogeneous environment. In contrast, the dehazing effect could be better in common complex natural scenes.

The atmospheric scattering model is shown in equation (1),

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

Where $I(x)$ is the foggy sky image，$J(x)$ is the clear fog-free image, A denotes the value of atmospheric light, and $t(x)$denotes the transmittance of the medium, so the goal of dehazing based on this is to calculate the value of atmospheric light and transmittance based on the existing foggy sky image, and thus estimate the fog−free image. When the distribution of particles in the atmosphere is spatially uniform, the transmittance $t(x)$ can be obtained by calculating the scattering coefficient β and the scene depth $d(x)$, as shown in Equation (2).

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

2.1. DCP dehazing method

In 2009, He et al. [1] proposed the dark channel prior (DCP) and found, based on a statistical analysis of data from thousands of clear fog-free images, that about 75% of the pixels have a value of 0 and 90% of the pixel points have very low values. Therefore, He et al. proposed that in local areas of daytime fog-free images (non-sky areas), pixel points with pixel values tending to 0 exist on at least one of the color channels. That is, for an observed image J is that

$$J_{dark} = \min_{y\in\Omega(x)}\left(\min_{c\in\{r,g,b\}}\big(J^c(y)\big)\right), J_{dark} \to 0 \tag{3}$$

Based on this prior it is possible to approximate the transmittance map $t(x)$and the atmospheric light value A. The formula for estimating the transmittance map $t(x)$is shown in (4), where the ω takes the value 0.95, and the A value is estimated by taking the top 0.1% brightest pixels in the dark channel map and finding the highest brightness point of these pixels in the original foggy sky image value as the atmospheric light value A.

$$\tilde{t}(x) = 1 - \omega \min_{y\in\Omega(x)} \left(\min_{c} \frac{I^c(y)}{A^c} \right) \tag{4}$$

The dehazing image can be obtained based on the existing equation (1), as well as the estimated transmittance map and the atmospheric light values.

$$\mathrm{J}(x) = \frac{\mathrm{I}(x) - \mathrm{A}}{\tilde{t}(x)} + \mathrm{A} \tag{5}$$

Although the overall de-fogging effect of the DCP method is good, it is less satisfactory for white objects and sky regions. And when estimating the window transmittance, the Softmatting algorithm used at the beginning could have been more efficient. He et al. subsequently proposed an improvement by proposing guided filtering instead of the Softmatting algorithm, which improved the estimation of the transmittance map and effectively improved the algorithm's efficiency.

2.2. CAP dehazing method

In 2015, Zhu et al. [2] proposed color attenuation prior (CAP) by finding that as the size of fog concentration changes, the luminance and saturation of foggy sky images also change, i.e., the scene saturation value is relatively large in the region without fog, and the difference between luminance and saturation is slight; the difference between scene luminance and saturation is significant in the region with thin fog; and the difference between scene luminance and saturation is most prominent in the region with thick fog. Thus, based on this characteristic that the scene depth has a proportional relationship with the difference between luminance and saturation, Zhu [2] et al. proposed to use a linear regression model to estimate the scene depth $d(x)$, as shown in Equation (6).

$$d(x) = \theta_0 + \theta_1 v(x) + \theta_2 s(x) + \varepsilon(x) \tag{6}$$

where θ_0、θ_1、θ_2 are unknown parameters, $\varepsilon(x)$ is the error term, $v(x)$ is the scene brightness, and $s(x)$ is the scene depth. Zhu et al [2] obtained the values of each parameter by supervised learning method for learning training. In order to prevent the influence of white objects, a minimum operation is required, so the estimated scene depth is finally obtained. Therefore, the deformation according to equation (1) can be obtained for the dehazed image.

$$\mathrm{J}(x) = \frac{\mathrm{I}(x) - \mathrm{A}}{min\{max\{e^{-\beta d(x)}, 0.1\}, 0.9\}} + \mathrm{A} \tag{7}$$

2.3. IDE dehazing method

In 2021, Ju et al. [3] proposed that the traditional atmospheric scattering model has inherent limitations: since the texture features will absorb the atmospheric incident light, and the absorption rate of light varies continuously with the density of texture features that it will have different lighting effects for different scenes, and the traditional atmospheric scattering model does not consider this practical point, thus leading to poor dehazing effects. Ju et al. [3], on the atmospheric scattering model, introduced a new parameter, light absorption coefficient $\alpha(x,y)$, to establish an enhanced atmospheric scattering model (EASM), as shown in Equation (8).

$$\begin{aligned} I(x,y) = A \cdot \big(1 - \alpha(x,y)\big) \cdot \rho(x,y) \cdot t(x,y) \\ + A \cdot \big(1 - t(x,y)\big) \end{aligned} \tag{8}$$

where the dim effect and light absorption intensity are enhanced as the light absorption coefficient $\alpha(x,y)$ becomes larger when the scene depth $d(x)$ decreases, so the light absorption coefficient $\alpha(x,y)$ is defined as

$$\alpha(x,y) = 1 - \frac{d(x,y)}{max(d)} \tag{9}$$

Therefore, bringing equation (2) and equation (9) into equation (8) yields that

$$\begin{aligned} I(x,y) = A \cdot \frac{ln\big(t(x,y)\big)}{ln(t_{min})} \cdot \rho(x,y) \cdot t(x,y) \\ + A \cdot \big(1 - t(x,y)\big) \end{aligned} \tag{10}$$

Ju et al. [3] proposed the IDE image-dehazing method based on the gray world assumption (GWA) and the improved atmospheric scattering model, which efficiently implements image-dehazing by estimating the values of each parameter term through a priori constraints and formula derivation with good robustness on foggy sky images of different resolutions and better color recovery for dim, foggy sky images. The IDE dehazing method takes into account the traditional atmospheric scattering. The IDE dehazing method considers the limitations of the traditional atmospheric scattering model and proposes an enhanced model worthy of further research and application.

3. Traditional image dehazing method based on image enhancement

Image enhancement-based dehazing methods do not consider the formation mechanism of fog, and improve the visual effect of the image by increasing the image contrast and saturation, but will cause a certain loss of detail information of the image. At present, the more common methods are histogram equalization-based dehazing, Retinex image enhancement dehazing and image fusion technology-based dehazing, among which the histogram equalization method can better improve the image contrast and achieve good visual effects, Retinex image enhancement method is more effective for low-light foggy day images, image fusion technology applied to image dehazing can The image fusion technique applied to image dehazing can remove the slight fog while retaining the detail information of the image.

3.1. Histogram equalization dehazing

Histogram equalization is global histogram equalization. Global histogram equalization is a process that changes the grayscale histogram of the original image from a relatively concentrated portion of grayscale to a uniform distribution of grayscale throughout, as shown in Figure 1. Global histogram equalization redistributes the pixel values of an image by non-linearly stretching the image so that the number of pixels in a given grayscale is approximately equal.

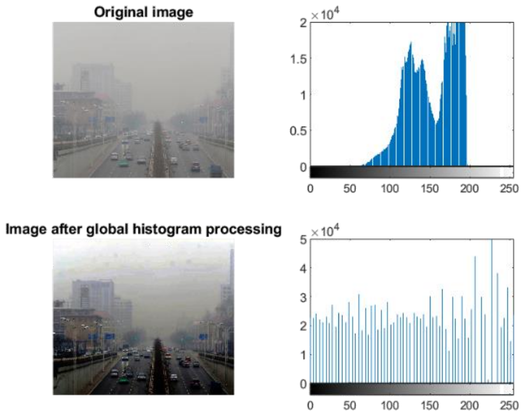

Figure 1. Global Histogram Equalization Process

Usually, foggy images are whiter than clear images, with lower contrast and more concentrated luminance values, expressed in the form of single or multiple peaks in the histogram and concentrated gray areas in the grayscale histogram. After equalization, the grayscale range of the foggy image is expanded so that the brightness of each pixel is more evenly distributed in the grayscale level, and the contrast and clarity of the image are enhanced after global histogram equalization, which can achieve a certain dehazing effect. The global histogram equalization algorithm usually directly processes the overall foggy image, which is suitable for the overall brighter or darker image and can effectively improve the image's contrast. Still, in most cases, the global operation tends to ignore local enhancement, resulting in the loss of local information and noticeable visual differences in local areas. The actual effect could be better. To solve this problem, Kim et al. [4] proposed a histogram equalization algorithm for localization, dividing the image into partially or non-overlapping local blocks and then performing histogram equalization separately to enhance local details.

3.2. Retinex image enhancement dehazing

Retinex theory suggests that the color and brightness of a point that a person can perceive is not determined by the absolute light entering the human eye at that point alone but is also influenced by the color and brightness of its surroundings. In other words, the image that people can see is the result of the combined effect of the reflected component of the object and the irradiated component of the light. Therefore, dehazing can be achieved by separating the irradiated component and the reflected component in the foggy image and suppressing the effect of the irradiated component.

Using the single-scale Retinex enhancement method alone to enhance foggy sky images has limited effect, and the results of dehazing are sensitive to the scale selection of the surrounding function. To avoid the drawbacks of the single-scale Retinex method, Xue et al. [5] proposed a multi-scale Retinex method to enhance the visibility of the image. Compared with the traditional Retinex enhancement method, this method has better results in image enhancement detail processing, color fidelity, and image distortion. However, the method has limitations regarding causing halos in the dehazed images. The method also requires artificial selection of the surround function and its corresponding size. Galdran et al. [6] provided a mathematical proof of the dual relationship between image dehazing and Retinex theory, which theoretically connects image dehazing and Retinex enhancement through a linear relationship, i.e., after pixel intensity, Retinex enhancement is used after inversion, and then intensity inversion. This method can be replaced using different Retinex enhancement algorithms, and advanced dehazing methods can be tried instead.

3.3. Application of image fusion technique to image dehazing

Image fusion uses image processing methods to fuse multiple images to reconstruct an image with better visual performance and complete preservation of detailed information. Therefore, after fully exploiting the information of the original image and obtaining multiple exposure images through the original fog map, image fusion techniques can achieve specific dehazing effects.

Galdran et al. [7] first introduced multiple exposure fusion based on the Laplace pyramid to image dehazing. Still, the Laplace pyramid fusion technique is a basic image fusion technique with a limited fusion effect and easy to causes the loss of boundary information. Zheng et al. [8] proposed to obtain the entropy value of image texture using the grayscale difference method after obtaining multiple exposure images using gamma correction. The decomposition of the image block into three independent components is performed to decompose the image block into three independent components, then processed separately and fused to obtain the final result. Liu et al. [9] proposed a joint contrast enhancement and exposure fusion framework that treats image dehazing as a local visibility and global contrast enhancement problem and then processed separately on three independent components. Liu et al. [10] used the gamma transform and saturation adjustment to produce a series of exposure images, image layer decomposition by bootstrap filtering, and then the construction of fusion weights and extraction of exposure features, respectively, and finally, the two layers of information are fused to obtain a dehazed image.

The dehazing method based on the image fusion technique focuses on the preservation of local details and contrast improvement of the image, which can effectively improve the performance and robustness of image dehazing. However, the fusion-based dehazing method is prone to the problem of excessive contrast amplification and color distortion in local areas.

4. Dataset and evaluation index

In conventional dehazing, the data sources relied on are extensive. Almost all foggy sky images under real-world conditions can be directly used as image-dehazing processing objects, so different researchers collect real foggy sky images from different sources. The more commonly used classical datasets are the 32 real fog sky images with different resolutions and scenes used in the experiments of Zhu et al. [2] and the RTTS dataset with more than 4000 real fog sky images collected from the web.

Currently, there are two leading evaluation indicators commonly used in the field of traditional image dehazing: first, image quality indicators, such as information entropy Entropy, BRISQUE, NIQE, BIQI, etc.; second, fog concentration evaluation indicators, such as FADE indicator, FRFSIM indicator, etc. In addition, the algorithm's complexity needs to be explored and analyzed in the image-dehazing process. Only by continuously optimizing the algorithm running time can it be better applied to the actual production life.

5. Conclusion

In this paper, we review traditional advanced dehazing methods in image dehazing, classifying and summarizing them from both image restoration and image perspectives. Image dehazing is a low-level vision task, and restoring a foggy image to a fog-free image is beneficial for subsequent high-level vision tasks. However, image dehazing faces complex and diverse image scenes, the limitations of dehazing models are apparent, and the dehazing work is very challenging. The traditional image dehazing field can build dehazing methods from these perspectives: more reasonable dehazing models, dehazing methods with more vital generalization ability, and more comprehensive evaluation metrics.

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