A Review on Haze Removal Techniques

K. P. Senthilkumar and P. Sivakumar

Abstract Images captured in outer environment suffer from reduced scene visibility, reduced color contrast, and increased color fading. This may happen due to the presence of haze, fog, smoke, dust and noise present in the outer atmosphere. Haze is formed due to two basic processes, attenuation and air light. Attenuation diminishes the contrast of the image and air light makes the image to be whiter and hence the image captured is unclear. Haze removal or image dehazing is required in real-world weather conditions to obtain a fast and high-quality hazy free image which is used in various fields like satellite systems and aircraft systems. The intention of this review paper is to give a brief analysis on different haze removal techniques.

Keywords Haze removal · Image enhancement · Dark channel prior · Filtering Genetic algorithm

1 Introduction

The main goal in image processing is to analyze, understand, and obtain information from the image. But in certain cases, images taken in outer air atmosphere under abnormal conditions (Fog, haze, dust, and smoke) degrade the nature of pictures. So there is a reduced contrast and deteriorates in color of the image obtained. When the separation between the object and the camera is increased, the clarity of the image obtained is automatically reduced. The visibility of the image is reduced when it is having poor illumination.

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J. D. Peter et al. (eds.), *Computer Aided Intervention and Diagnostics in Clinical and Medical Images*, Lecture Notes in Computational Vision and Biomechanics 31,
https://doi.org/10.1007/978-3-030-04061-1_11

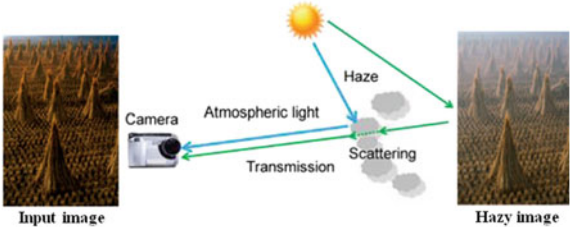

Fig. 1 Haze model. (Reproduced from Chen et al. [1])

1.1 Formation of Haze

Haze is an outer atmospheric phenomenon that partially covers the sky region and produces thin and very translucent effect. It is an aerosol having a radius of 2–10 μm and it is more brownish or bluish. Haze is produced due to two important phenomena attenuation and air light. The image captured under that situation got attenuated in the line of sight distance and reduces the color similarly air light effect adds the light from all other directions and it increases the whiteness in the image. The effect is shown in Fig. 1.

The presence of molecules count in the outer atmospheric region varies depending on the weather conditions. Haze, fog, and smoke come under the category of steady weather conditions, and snow and rain come under the dynamic weather conditions. In the haze environment, the illumination obtained in the image is varied because of considerable molecules count and the aerosols present in the outer environment. In haze environment, the images captured will have poor visibility and those images are considered as poor intensity and low contrast images. The content of the paper is organized in the following manner Sect. 2 gives the mathematical standard and haze removal methods; Sect. 3 elucidates various haze removal methods, Sect. 4 elucidates the study of various haze removal methods, Sect. 5 gives the various performance parameter calculation, Sect. 6 lists the various applications of haze removal methods, and Sect. 7 ends with the conclusion of the paper.

2 Mathematical Standard and Haze Removal Methodology

Haze model is universally used in several image processing, remote sensing, and different computer applications. This model is used for the image formation under very bad weather conditions, so image quality is very much reduced by the existence of haze, smoke, and fog.

Assume that the model of haze is linear, as per the definition of linearity, the position of the pixel in the image is changed. The mathematical model of hazy component is given by

$$X_C(P) = Z_C(P)t(P) + A_C(1 - t(p)) \tag{1}$$

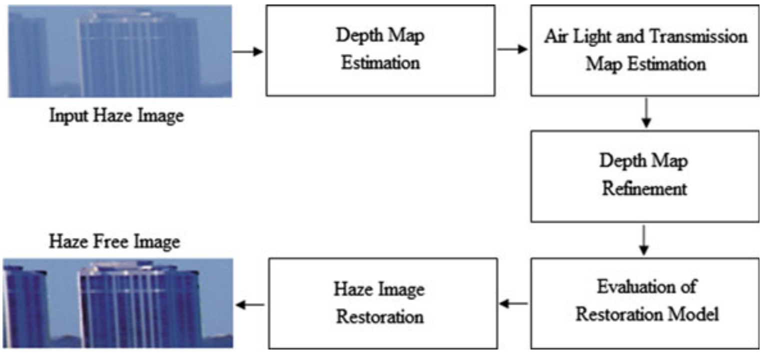

Fig. 2 Haze removal methodology

$$t(p) = e^{-\alpha d}(p) \tag{2}$$

where C is the color index of the channel (R, G, B), A_C indicates the global atmospheric light, Z_C indicates the image without haze, t is the medium transmission, $Z_C(P)t(P)$ gives the attenuation parameter, $A_C(1 - t(p))$ is the airlight, d(p) is the unknown depth information, and α is the scattering coefficient. The step-by-step haze removal from an image is explained above in Fig. 2. Air light and transmission map are evaluated in depth map estimation as the first step of haze removal methods. Depth estimation includes optical model, refined optical, restoration of perceptibility, preexistent dark channel, and preexistent color attenuation. Refinement of depth map is followed after depth estimation which is a technique used to reduce depth map errors, noise and undesired artifacts. Restoration of haze-free image is adopted using haze image restoration as the last step in the frames of reference and the mathematical standard for restoration is given by

$$Z_C(P) = X_C(P) + (1/t(p) - 1)(X_C(P) - A_C) \tag{3}$$

where $1/t(p) - 1$ is amplification factor and $(X_C(P) - A_C)$ is the detail layer, and Z_C is the restored image. The objective of the method is to obtain the restored image Z from the haze image X. The restored image has improved contrast and it is free from haze and noise.

3 Haze Removal Techniques

Many haze removal methods were proposed to remove haze from single and multiple images. Haze removal methods have increased both neighborhood and total contrast of the scene and also it corrects the color distortion and provides depth information and visually pleasuring image. The hazy image and the dehaze images are shown in Fig. 3.

Fig. 3 Original input image and restored image. (Reproduced from Shen and Wu [2])

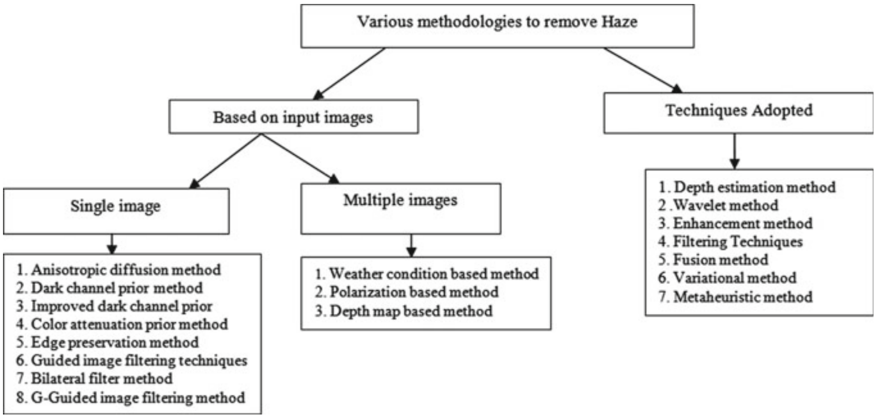

Fig. 4 Various haze removal methods

Dehazing techniques depend on the number of input images used and the methods are classified into (1) Multiple images dehazing and (2) Single image dehazing. Generally, removal of haze techniques are classified into various extended classes. Those methods are listed as (1) Depth estimation method (2) Wavelet method (3) Enhancement method (4) Filtering Techniques (5) Fusion method (6) Variational method, and (7) Meta-heuristic method. The various methods are shown in Fig. 4.

3.1 Multiple Images Based Haze Removal

In weather condition based method [3, 4], they used two or more scenes and they found the difference between the characteristics of the images but it does not give the better results. In polarization-based method [5], they used different scene images captured with various polarized filters but it has failed for dynamic images and images with dense haze. In depth based method [6], they used the 3D geometrical model and texture of the scene and also provided a good result, but it was not automatic. The comparison is shown in (Table 1).

Table 1 Multiple images based haze removal

Methods	Features	Drawbacks
Weather condition method	Used two or several images of the same scene under various climatic situations, also enhanced visibility was obtained	Impotent to handle the dynamic scene and does not give the result suddenly
Polarization method	Used several images taken with polarization filter captured in bad climatic situations and it has applied at any time instant	Unable to manage very dense hazy image and dynamic images
Depth model method	Used the 3D geometrical model and texture of the image and gave accurate results and scene depth	Not automatic

3.2 Single Image Based Haze Removal

Dark channel prior method (DCP) [7] was utilized to eliminate haze from images where some pixels in image have less intensity in any one color channel where the region of sky was not covered called as dark pixels, used to calculate the transmission map then they derived the refined transmission map to remove the haze effect. Here, transmission map was estimated accurately but it produced some halo effects in the output image. Modified dark channel prior method was the improved method of (DCP) which used bilateral filter for soft matting which smoothens the small-scale texture of the images. They utilized the DCP concept to calculate the atmospheric veil under the presence of sky region. The result obtained has greater efficiency, less execution time, and accurate results, but it produced halo artifacts in some regions and transmission map was not found accurately. In anisotropic diffusion method [8], the atmospheric light obtained by DCP method, improved contrast of the image was obtained without user interference. The air light was estimated accurately with contrast-enhanced image but visibility of the restored image was poor. Color attenuation prior method [9] was used to create an exclusive model of the scene depth information of the haze image, using supervised learning method. They obtained the recovered depth map which was used to recover the scene from the hazy image. The output obtained has high efficiency and good dehazing effect. Edge preserving decomposition method [10] was used to calculate the depth map for a hazy image which was based on two important principles modified color channel and simplified dark channel. The result obtained was accurate and was widely used in single image haze removal. The bilateral filter method [11] calculates the output of a pixel by its averaging of nearest pixel, it smoothens the haze image while conserving the boundary, and was widely used in noise reduction and image compression. The major drawback was that it produces gradient reversal artifacts in the output images.

The GIF [12] was derived from a regional linear model and generates the reference image which may be primary image or other different image and it preserves the edges of the image like bilateral filter which has O(N) computation time and has higher efficiency. The guided image filtering (GIF) and weighted guided image filtering does not preserve fine structure so globally guided image filtering was proposed [13] which was composed of a global structure transfer filter and a global edge preserving smoothing filter which was used to produce sharper images and visible fine structure. The comparison is shown in (Table 2).

Table 2 Single image based haze removal

Methods	Features	Drawbacks
Anisotropic diffusion method	It reduces haze without removing edges and lines from images and air light was estimated accurately	Transmission map was not estimated accurately and restored image visibility was poor
DCP method	Dark pixels was utilized to assess the depth map, also refined transmission map was estimated to remove the block effects	Halo effects were produced in the resultant image
Improved Dark channel prior method	Improved version of DCP method which used bilateral filter for matting. Estimation of air light was accurate and it has greater efficiency, less execution time	Halo effects were produced in some regions in resultant image and transmission map was not estimated accurately
Color attenuation prior method	A novel method for haze removal and powerful tool for scene depth estimation. It has high efficiency and good dehazing ratio	Average speed and large haze gradients
Edge preserving based method	The edges were preserved and accurate result was obtained	Average speed, halo artifacts, and large haze gradients
Bilateral filter method	Edges were preserved and air light was estimated accurately	Gradient reversal artifacts and poor speed
Guided image filter method	This filter has fast linear algorithm and computational complexity was independent of kernel size, also it preserved the edges	Halo artifacts problems and no fine structure preservation
Globally Guided image filter method	It is composed of a global structure transfer filter and global edge preserving smoothing filter, which preserves the fine structure of dehazed image	Color distortion problems

3.3 Techniques Adopted

In depth based estimation haze removal method, to evaluate the atmospheric veil, multi-scale tone method [14] was used to measure the nature and luminance of guidance image at different scale levels. But this method does not attain the true results for excessive hazy images. In wavelet method, improved wavelet transform [15] was used for efficient haze removal. In this method wavelet, transform was used in the initial stage to remove the haze and then Retinex algorithm was used to enhance the color performance and upgrade the color response in the restored image. In another method, fast wavelet transform technique [16] was introduced to improve the running time without any prior, and haze was completely removed and also sharpening of image was obtained simultaneously. In enhancement method, dark channel prior was used which utilized the soft matting method but it needs more memory and time and it was used for images which was very small only. In filtering method, the median filter and gamma correction [17] were used to construct a look-up table to determine the nature of restored images. This method has less calculation time and it enhanced the brightness of the image, but it does not preserve the corners in the restored image. The guided joint bilateral filter [18] was used to recover neighborhood smoothening as well as the preservation of edges, but this method also suffered from halo artifacts. The weighted guided image filtering method [19] used a familiar weight methodology to improve the filtering process and also it overcomes the problem of light line around the edges of the image. This method has a minimum calculation time when compared to other methods and also it increased the illumination of the restored image. An image fusion technique [20] was used in which it fused the output of guided image filtering, by a linear transformation method then an improved high boost filtering method is used to obtain the second input image which is used for the fusion process. This method improves the visual clarity of the images and it has increased running time efficiency. The variational method can overcome the drawbacks of physical assumption and over enhancement problem. Fang et al. [21] have designed a new method to remove haze from the images and also they removed the noise from an image, then base layer was also improved by using various techniques based on dark channel prior which removes segment artifacts problems. Galdran et al. [22] developed an energy utilization model which depends on hazy image in gray model, calculating an average value for restored image, but unwanted artifacts were found in closed regions. In the meta-heuristic method, they used genetic algorithm [23] for the haze removal to select the best parameters for producing the optimistic results. The genetic algorithm attains the best haze removal parameters but it does not guarantee the flawless solution.

4 Analysis of Various Haze Removal Methods

The analysis of various Haze removal methods is shown in Table 3.

Table 3 Analysis of various haze removal methods

S. no	Haze removal methods	Preservation of edges	Halo artifacts	Running time	Advantages	Applications
1	Variational dehazing	Yes	No	Moderate	Reduced over enhancement problem	Natural images
2	Dark channel prior	No	No	Poor	High-quality haze-free image	Outdoor images
3	Bilateral filtering method	Yes	No	Poor	Efficient noise suppression, no color drift	Underwater image enhancement
4	Fast image enhancement	No	No	Moderate	Zero color distortion	Intelligent transportation system
5	Improved wavelet transform	Yes	No	Good	Efficient noise suppression	Natural images
6	Color lines based haze removal	No	No	Medium	Used for thin haze	Natural images
7	WGIF method	Yes	Yes	Excellent	Efficient noise suppression	Underwater images
8	Edge preserving	Yes	Yes	Moderate	Edges are preserved perfectly	Outdoor images
9	Improved dark channel prior	Yes	Yes	Good	Efficient noise suppression	Natural images
10	Genetic algorithm	Yes	Yes	Average	Optimistic results	Natural images
11	GGIF	Yes	Yes	Good	Edges are preserved perfectly	Underwater images

5 Performance Parameters

Performance parameters or metrics are used mainly in haze removal algorithms to check or analyze or reporting the quality of dehazed image. The important quality measures of an image are given by (1) Mean square error (MSE) (2) Peak signal-to-noise Ratio (PSNR).

5.1 Mean Square Error (MSE)

Mean square error is calculated between hazy image and the input image. It is calculated by using equation

$$MSE = 1/MN \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left((C(x, y)) - \left(C^{*}(x, y)\right)^{2} \right) \quad (4)$$

Here M and N are the input image apex and broadness, *C(x, y)* and $C^{*}(x, y)$ are restored image and original image.

Higher values of MSE indicate that low quality of image is obtained.

5.2 Peak Signal-to-Noise Ratio (PSNR)

Peak signal-to-noise ratio is calculated with respect to input image and hazy image and it is given by

$$PSNR = 10\,log\left(255^{2}/MSE\right) \quad (5)$$

The higher value of PSNR shows that the image quality is very good.

6 Applications of Haze Removal Methods

Removal of haze methodology plays a vital role in many image processing areas. Some of the wide important areas in which the haze removal methods used are aircrafts, remote sensing, intelligent transportation systems, underwater image processing, Object detection, outdoor surveillance, railway systems, aerial imagery, image processing and video retrieval, computational photography/vision applications, video analysis and recognition, image classification, military and defense surveillance system, etc.

7 Conclusions

This paper presents various simple and faster haze removal methods which are used in several important applications. Various haze removal methods have been analyzed which gives a clear idea of how haze reduces the visibility of the images captured in outdoor environment. Haze removal from a single image is a very tedious work due to the calculation of scene depth map and also it requires certain prior knowledge. Also, it is very important to conserve the edges, illumination of the images, color characteristics, and appearance of the dehazed images. In future, various filtering methods have to be developed which gives optimal evaluation of depth map and to increase PSNR value with increased image quality and good running time.

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