Single Image Dehazing Using Haze Veil Analysis and CLAHE

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Abstract. Images of the outdoor scene appear hazy due to degradation occurred by atmospheric particles (water droplets, dust, etc.) while capturing the image. Hazing creates lots of problem in the areas of surveillance, tracking and navigation and other applications. Dehazing such images is desired in digital photography and computer vision. Thus, to remove it from an image, single image and multiple images defogging methods have been proposed in the literature. In this paper, we present a single image dehazing approach using haze veil analysis. Contrast limited histogram equalization (CLAHE) technique is used to improve the contrast of the image. The proposed method has been evaluated on different foggy/hazy images. The proposed system yielded better results in terms of preserving the finer details and the color quality of the images.

Keywords: Dehaze · Haze Veil · CLAHE · Contrast Stretching · RGB · YCbCr

1 Introduction

Image processing techniques are widely used to enhance the quality of digital images captured outdoor or indoors. The quality of outdoor images captured is generally degraded due to atmospheric particles scattering the light (bad weather conditions such as fog and dust particles that absorb and scatter light) of the object image in the line of sight. Also, due to defects or movement in capturing device or moving objects, images may get blurred [1, 5]. Further, the images captured in dark or night appear washed out or noisy [2].Images that are foggy or images captured in the haze makes it difficult to identify the objects from those images [3, 4]. Foggy images appear noisy making it difficult in object detection, recognition, and image visualization. Noise-free images are desired in many applications including name plate detection, medical image analysis, surveillance applications and tracking and navigation applications [6]. Image enhancement plays a vital role in improving the quality of images by dehazing or defogging the captured images.

Several single image and multiple images de-hazing techniques have been proposed in the literature [7, 8].A model is proposed in [9] to remove haze from the region of river/sky alike scenes using image negative concept. K-means clustering is used to extract internal and external clues to enhance dark channel values for reconstructing an enhanced

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image. An algorithm is proposed to preserve the brightness of an image using histogram equalization in [10].

Many of the single dehazing methods use dark channel prior (DCP) approach introduced by He.et. al. [11]. In several cases, DCP approach produces artifacts around regions where the intensity changes abruptly. To eliminate the artifacts He et al. [12] proposed a soft-matting process that suppresses halos and block artifacts. Gibson et al. [13] proposed a DCP method based on the median operator. Zhu et al. [14] introduced linear color attenuation prior, and Ren et al. [15] used a deep multiscale neural network.

This paper presents a single image dehazing method based on haze veil concept introduced by Fan Guo et.al. [16]. The contrast of the de-hazed image is improved using Contrast Limited Adaptive Histogram Equalization (CLAHE) [21] technique. Experimental results demonstrate the effectiveness of the proposed method, and when compared with other methods, the proposed method achieves a higher restoration quality. The paper is organized as follows. In Sect. 2, the methodology is discussed. In Sect. 3, experimental results and analysis are shown. The conclusions are described in Sect. 4.

2 Methodology

The proposed methodology is based on haze veil analysis introduced by Fan Guo et.al. [16]. The method regards haze as a veil layer. Illumination image is generated using retinex algorithm and depth information of the original image is used to remove the veil layer. Lastly, CLAHE technique is applied to the haze removed image to get a clear image. The proposed method is described below.

3 Haze Veil Calculation

Retinex theory deals with compensation for illumination effects in images. Accordingly, the input image, S, can be described as product of reflectance image, R, and illumination image, L, at each point (x,y).

$$\mathrm{S(x, y)} = \mathrm{R(x, y)} * \mathrm{L(x, y)} \tag{1}$$

where * is the convolution operation. The illumination component can be estimated using smoothening technique. The process involves applying a smoothening function to degraded image to obtain illumination image and is expressed as.

$$\mathrm{L(x, y)} = \mathrm{S(x, y)} * \mathrm{F(x,\ y)} \tag{2}$$

$$Where,\ F(x, y) = Ke^{\frac{x^2+y^2}{\sigma^2}}$$

where, K is the normalizing factor and σ is the standard deviation. With w x w window, K is determined so that F(x, y) equals one. L(x,y) is the haze veil assuming the haze is uniform. However, to compensate for color, the uniform haze veil, the degraded image is multiplied by mean of the illumination image to obtain depth-like map as follows

$$L'(x, y) = 255 - S(x, y) * \hat{L}(x, y) \tag{3}$$

where,

$$\hat{L}(x, y) = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} L(x, y)$$

And M, N represents number of rows and columns of pixels respectively [18]. For obtaining the final haze veil, $L\prime(x, y)$ is converted from RGB to YCbCr color space and the illumination component from converted space is extracted (Fig. 1(b)). In YCbCr, Y represents luminance component, Cb is difference between blue and luma component and Cr difference between red and luma. Cb and Cr are chromium components. YCbCr component separation of image is given below.

$$\mathrm{Y} = 0.299\mathrm{R} + 0.587\mathrm{G} + 0.114\mathrm{B} \tag{4}$$

$$\mathrm{Cb} = \mathrm{B} - \mathrm{Y} \tag{5}$$

$$\mathrm{Cr} = \mathrm{R} - \mathrm{Y} \tag{6}$$

3.1 Computing Reflectance Image

In most Retinex algorithms, the image is converted into logarithmic domain. Accordingly,

$$\mathrm{LogS} = \mathrm{logR} + \log \mathrm{L} \tag{7}$$

The reflectance image is then extracted using the expression.

$$R' = exp(logS - Log') \tag{8}$$

Our $R\prime$ represents the haze removed image (Fig. 1(c). Further, image enhancement is carried out as post processing step in order to get clear visual image. For this, we use histogram based technique. Histogram techniques are regarded as simple methods used to enhance the contrast of the image thereby improving the image quality. Many algorithms have been proposed in the literature based on histogram approach [17, 19, 20]. CLAHE an adaptive extension of Histogram Equalization followed by thresholding is a technique which helps in the dynamic preservation of the local contrast features of an image [21, 22, 24]. It operates small regions in the image, called tiles. The contrast enhancement is limited by clipping the histogram through user defined values known as clip limit which describes the amount of noise to be smoothened for contrast enhancement. The technique preserves sharpness details. The method also increases the local contrast pixels. CLAHE has been adopted in our work to enhance the visual quality of the de-hazed image. In RGB color model, CLAHE can be applied on all the three components individually. The result of full-color RGB can be obtained by combining the individual components. In the proposed methodology, CLAHE is applied to reflectance RGB image which yields better haze free image (Fig. 1(d)).

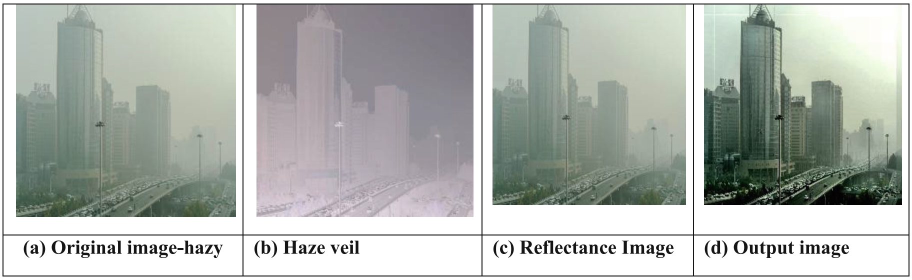


Fig. 1. Sample image illustrating dehazing process

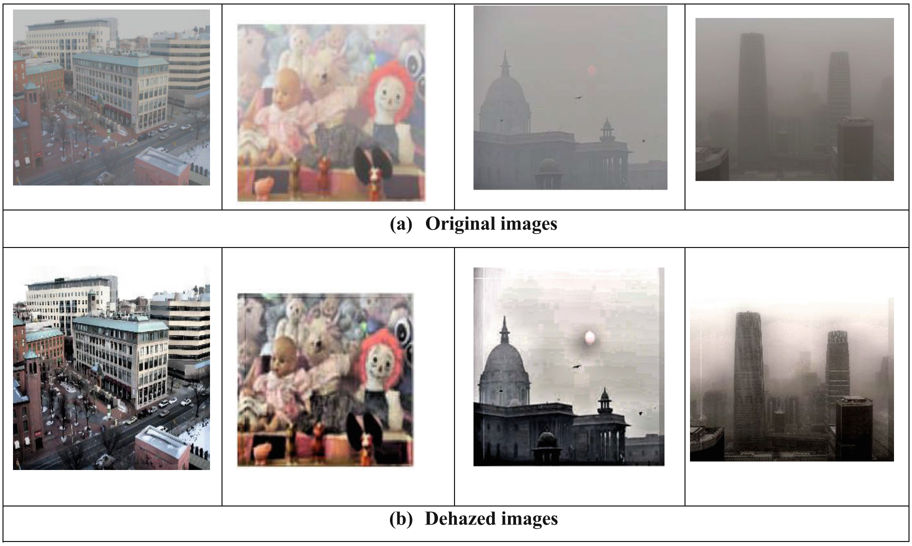


Fig. 2. Dehazed image samples illustrating dehazing process using proposed method

4 Experimental Results

The proposed methodology yields good results for different hazy images. Sample images are shown in Fig. 2, The resulting images are compared with images obtained by applying different methods presented in the literature. Sample images are shown in Fig. 3.

The results analysis is done in terms of the parameters, PSNR and MSE. "Peak signal-to-noise ratio is the ratio between the maximum possible power of an image and the power of corrupting noise that affects the quality of its representation."

$$PSNR = 10log_{10}(\frac{L-1^2}{MSE}) \tag{9}$$

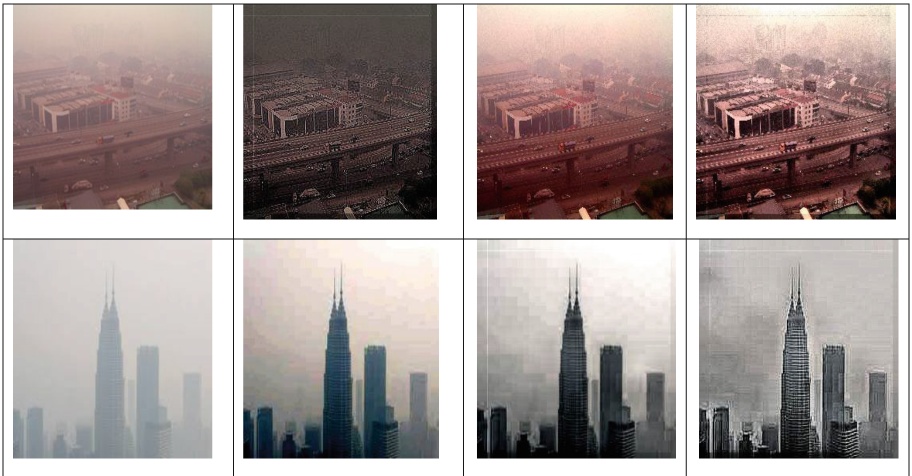
where, L is the maximum possible intensity levels, and Mean square error (MSE)

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}(O(i,j) - I(i,j))^2 \quad (10)$$

where, m, n represents number of rows and columns of pixels respectively. i, j represents index of rows and columns of pixel respectively. O represents matrix data of original image, I represents matrix data of Input image.

The PSNR and MSE values computed for sample images and its comparison with other methods in the literature is given in the Table1.

The proposed methodology is applicable for single image haze removal and the output images provide better result compare to original haze veil analysis [12] and [13]. Here, PSNR values and MSE values show better performance of the proposed method to yield haze free image as an output.



(a) Original Image | (b) Haze Veil | (c) Fusion based CLAHE | (d) Proposed (modified HazeVeil)

Fig. 3. Dehazed image samples illustrating dehazing process using different methods

Table. 1. Comparative analysis for proposed method

Method	Image1		Image 2	
	PSNR	MSE	PSNR	MSE
Haze Veil and adaptive contrast strecthing[16]	27.89	100.93	27.76	105.70
Fusion based CLAHE [23]	28.10	98.04	27.66	111.44
Proposed	**28.34**	**95.19**	**27.90**	**105.28**

5 Conclusion

Image Dehazing is one of the challenging issues in digital image processing applications. The paper presents an approach to get dehazed image using haze veil analysis and CLAHE. Here, Haze Veil layer is eliminated from original image and enhanced using CLAHE technique. The results are better than original method because of using CLAHE technique which enhances image adaptively based on clip limit and stops over amplification. The proposed methodology in comparison with existing methods provides better PSNR values, colorfulness and contrast enhancement resulting in better quality dehaze image. The method is applicable for single image and uniformly distributed haze.

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