Single Image Dehazing Using Dark Channel Prior and Type-2 Fuzzy Sets

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Abstract: Images taken in hazy conditions frequently suffer degradation and makes it difficult for identifying objects in the image. Many methods have been put forth for haze removal in the works of literature. Many of them over saturate the images after haze removal and thereby resulting in poor quality images. Images having better edges, brightness, and the ability to keep the original colour of the image must be retrieved. One of the finest algorithms to reduce haze from images is the dark-channel prior technique. This study uses dark-channel prior for fog removal and fuzzy edge detection techniques has been presented to keep the image's edges sharp. Performance evaluation metrics used demonstrate the effectiveness of proposed method.

Key-words: Hazy image**,** *Dark Channel Prior, atmospheric light, transmission map, Fuzzy edge detection.*

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1. Introduction

Images captured outdoor serve many purposes including recognition, detection, and surveillance. However, atmospheric particles (haze, fog, mist, etc.) affect the visibility of the images captured thereby making it difficult to process the images further.

Picture quality is essential in order to extract and analyse information from digital images. Low contrast caused by poor weather, such as haze, fog, and mist, among others, commonly affects outdoor scenes and films. Haze can be generated by Smoke, dust, and other dry airborne particles, which reduces atmosphere's clarity [15][16][17].

Achieving the high accuracy in haze removal is challenging. The objective may be described as improving hazy images while recapturing the original image with the least degree of information loss. Inadequate object visibility causes the loss of critical data that are critical to several applications like traffic and target detection.

During the available research, a number of techniques have been recommended for haze estimation and removal [18]. These techniques provide de-fogged images with better visibility. After elimination of the fog/haze, enhancing an image is important to increase the image's visibility. In this article increase in visibility of defogged image is done using fuzzy edge detection technique to preserve the outlines of the scene's objects. Results are analysed using performance metrics PSNR and SSIM.

2. Literature Review

Many of the single dehazing methods use dark-channel prior (DCP) technique introduced by He.et al. In several cases, The DCP technique creates artefacts in the area of places where the intensity varies suddenly. Using the median operator as the foundation, Gibson et al. suggested a DCP technique. Whereas Zhu et al. employed linear colour attenuation previously.

Single image –dehazing is based on Tan approach. This methodology is formed by an optical model which is made up of two terms Direct attenuation and airlight, respectively. He continued by defining it as colour vector components and light chromaticity. The foundation of the suggested method is the presumption that images taken on a clear day have more contrast than those taken during inclement weather. Tan used this supposition to eliminate the haze from the restored image by enhancing local contrast.

The Kopfetal [2] approach is formed on a 3D representation of the outside scene or images. This technique does not call for several pictures of a similar scene taken at various polarization levels. The structure of the real world is considerably different, which is method's basic problem. The success of this strategy solely depends on the application. It implies conversing with an expert.

A study on Single picture haze reduction using dark channel prior approach was proposed by K.He et.al. In this investigation, the haze was removed utilising the dark-channel prior approach, from an individual image. Using this technique, researchers were able to get haze thickness and a clear, high-quality image. Mostly absorption and reflecting make up images. This causes the image to lose contrast and colour accuracy. Therefore, by removing this atmospheric effect, or fog, the sharpness of the image will be visible and clear. Comparision is done for improved restored image's. This approach can be used to locate distant objects under thick haze. However, in a big area, it is comparable to airlight. To clear the image of the haze, they employed image texture maps and 3D models.

J-Hwan et.al suggested Dehazing of a single image technique developed using improved contrast. On a particular image, a suggested technique for contrast enhancement is presented. One hazy image is subjected to this method. The initial phase is based on quad-tree subdivision, airlight estimate. Subsequently, optimum transmission is with the persistence of making the improved image's with advanced contrast. Airlight is only source for ambient light in environment. In a picture, it is regarded as the lightest colour. For the purpose of estimating airlight, they employed an approach to hierarchy that employs on quad-tree subdivision. The method calculates space-varying transmission value. In order to increase the image's contrast, an input image is separated into several blocks and estimates are made. Since videos use more power than single images do, we can apply low complexity algorithms to them as well.

Feng Yu et.al presented Viewbased cluster segmentation for image and video dehazing. The sky and white objects are made apparent and distortion in sky areas is avoided using a viewbased cluster segmentation method. In this instance, the sky region may be estimated from a distance is changed to prevent distortion and the depth is first clustered using a GMM (Gaussian Mixture Model). Second, K-classifications are separated from a single blurry images, and third, video dehazing is done using an online GMM cluster. Here, a method is suggested that uses a GMM cluster, colour attenuation prior, and transmission estimation and atmospheric light estimation individually for the hazy image and depth map. In order to reduce colour distortion and improve overall contrast, this approach is updated utilising viewbased cluster segmentation, and a method for dehazing of videos is given employing an online GMM cluster.

Yongmin Park et.al presented a rapid implementation methodology for dehazing outdoor videos using dark-channel priors. It achieves the swift implementation of the dark-channel priors approach aimed at the dehazing of outdoor footage. While maintaining the original method's dehazing quality, up to 49% less execution time is utilized generally. The signal processing method known as "dehazing" is used to remove haze. Every pixel in the picture has a different level of haze density. Therefore, finding the black pixel in a picture clears out any haze. Camera records the blurry image and locates the airlight. A cost function made up of a term for the standard deviation and a term for the histogram uniformity is developed to assess the contrast. Finally, testing results show that the suggested method can recreate the features in the original sceneries more clearly while also removing haze.

Sarit Shwartz [7] As a result of attenuation and dispersion under foggy conditions, outdoor images have low contrast. The change in spatial contrast minimization caused by airlight scattering from atmospheric fog particles that are approaching the camera is a key issue. By creating an image's depth map, current computer vision algorithms have demonstrated that images are reimbursed for haze. The first stage in such subtraction is recovering atmospheric light from the scene. It is obtained by locating a picture that has been polarization-filtered. Information about airlight is necessary for the recovery. In earlier investigations, these specifics were calculated by counting the pixels in images of the sky. Through the proposed technique, the details required for removing airlight from computations which are reconstructed without vision are achieved, followed by the recovery of contrast without user input, as well as the presence of the sky in the frames. Therefore, it's necessary to satisfy the attenuation and scattering coefficients in order to dehaze the foggy image.

Ms.S.Archana M.E proposed the application of a depth map to recover depth information, an adaptive linear model with colour attenuation prior features, the accurate elimination of haze from the image and a simple method to reconstruct scene radiance using a tropospheric dispersion model. The basic image may be easily recovered using the depth map. Despite finding a technique for the brightness and saturation of the foggy images to create the scene depth, the issue still persists. Since it remains constant under identical air circumstances, the scattering coefficient cannot be restarted. There is a need for a highly flexible model since the single image dehazing techniques now in use rely on continuous conclusions.

Manjunath.V [9] Modifying a detail algorithm is a simple yet effective previous technique for dehazing a single image. Due to the multiple scattering method used in this algorithm, every input images looks slightly blurry. Dehazing becomes incredibly simple and effective when this approach is used with the single picture dehazing model. The system, which uses more types of images and is built on regional information, is more delicate than colour. Many physical models are employed to solve this issue. Because of air layer particles like fog, haze, etc., imaging under wet weather conditions is frequently harmed by dispersion.

Yu Li [10] a model of haze for different light sources and haloes was presented which features halos and contains an airlight and transmission map. A halo image is the input. Additionally, it is separated in a halo and haze-free pictures utilising an optimisation problem. The halo-free photos are processed in advance. The primary responsibility in this technique is transmission map's estimate and airlight. This approach seems to be simple and economical. But haze-free outcomes are subpar in comparison to other approaches.

Using the dark-channel priors for dehazing of a single image approach introduced by He et.al. is presented. Edge preservation is done using fuzzy edge detection method [24]. The proposed method yields a better restoration image quality which is compared to other methods in the literature.

3. Methodology

The suggested technique is usually formed on the basis of Dark-channel prior method. Block diagram of the suggested methodology's is displayed in Figure. 1. The approach uses foggy photos as its input; it then separates the colour components, estimates the transmission map and atmospheric lighting from the components. Type-2 Fuzzy set canny Edge detection technique is used to improve the detection accuracy. Following is the detail presentation of the method.

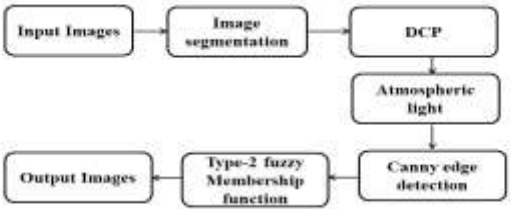


Figure 1: Representation of the Proposed Method

3.1. Dark-Channel Priors

The dark-channel is described by He et al. [3] as:

$$J^{dark}(X) = \min_{c\in\{r,g,b\}} \left(\min_{y \in \Omega(x)} \left(I^c(y) \right) \right) \quad (1)$$

I^c is a red, green, and blue colour channel of I, and (x) is a local patch that surrounds the pixel at x. The expected dark channel of I is J^{dark}. The ambient light is assessed using J^{dark} by locating the the pixels with the greatest 0.1% values, same like in eq (2). Frequently pixels are usually hazy opaque. Several haze-removal techniques identify those pixel with maximum, which is often unsuitable, and use that data to figure out how much airlight is there. Memory contains the following pixel indices from the top 0.1%

$$m = \underset{\tilde{x}\ \ 0.1\%}{arg\,max} \left(J^{dark}(\tilde{x})\right) \qquad [2]$$

The values of the three colour channels in I(m) are then summed altogether. Eventually, the A pixel is chosen to represent the highest total as follows:

$$A = \underset{\tilde{I}}{\arg max} \left(\sum_{c\in\{r.g.b\}} \tilde{I^c}\,(m)\right) \qquad (3)$$

The normalised dark channel is defined by using I and the estimated A as follows:

$$J_N^{dark}(X) = \underset{c\,\in\,\{r,g,b\}}{min} \left(\frac{I^c(X)}{A^c}\right) \qquad 4)$$

subsequently, it is presumed that the coarse transmission is ~t:

$$\tilde{t}(X) = 1 - \left(w \times \underset{y\,\in\,\Omega(x)}{min} \left(J_N^{dark}\,(y)\right)\right) (5)$$

while ω in He et al. [3] 0.95 is chosen as the value for the aerial perspective factor. To smooth down the noisy, incoherent transmission map that is produced as a result of Ke and Chen's [24] technique, which starts with a dense field based on pixels a moving average filter is applied. The outcome, known in [3] as the refined (improved) transmission map t, is produced by both methods almost exactly in the same way. J is recovered using the improved transmission t and A as follows:

$$J\,(X) = \frac{\mathrm{I}_{(X)} - A}{max(t(X)\,, t_0)} + A \qquad (6)$$

In He et al. [3]'s study, t0 is set to 0.1 in areas where the transmission map value is less than 0.1. Ke and Chen's [24] Dark-channel estimation was based only on data from the pixel's least-color channel since soft matting necessitates intensive calculations and memory. After estimating A using Equations (2) and (3), Equations (1) and (5) in [11, 12, 13] became:

$$J^{dark}\,(X) = \underset{c\,\in\,\{r,g,b\}}{min} \left(I^c\,(X)\right) \qquad 7)$$

3.2 Atmospheric-light Estimation

When creating the ambient light with a substantial local patch, it is possible to compute the ambient light accurately from dark-channel. As a precaution, if the huge local-patch size applied to construct the Dark-channel is insufficient, a second dark-channel with a huge local-patch size should be used to estimate atmospheric light. It is demonstrated that using local entropy effectively improves estimation accuracy by allowing for the avoidance of ambient light estimation from bright objects.

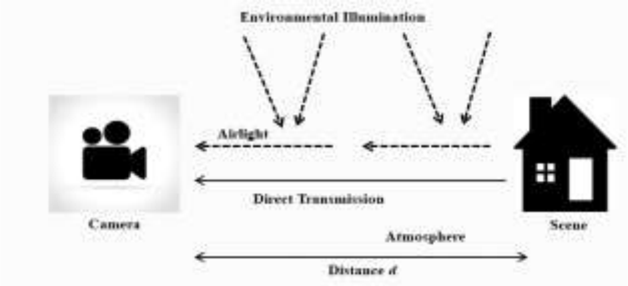


Figure-2: Refraction of light from air particles

The following is a description of the ambient scattering of light model in computer vision (Shi et.al (2018), Kim et. Al (2019), Lee et.al (2020))

$$\boldsymbol{I_{(p)} = J_{(p)} t_{(p)} + A\left(1 - t_{(p)}\right)}$$

In this equation, (A) stands for atmospheric light, R(p) for pixel p intensity, J(p) for the output image, I(p) for the input image, and t(p) for the transmission map .

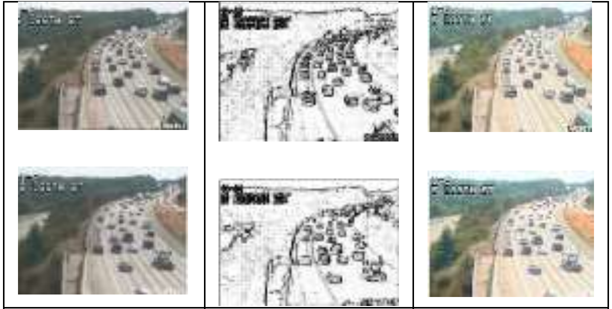
3.3. Type -2 Fuzzy set

Edge detection in images is made possible using fuzzy logic for image processing. When two uniform zones converge to create an edge, the intensity of the adjacent pixels can be used to identify the edge. Little intensity variations between two nearby pixels do not, however, necessarily signify an edge since uniform zones are not well defined. Alternatively, the disparity in intensity can signify a shading effect. The amount in which a pixel is a part of an edge or uniform area may be determined using membership functions when using fuzzy logic for image processing.

In order to recognise edges in grayscale images, the well-known and a efficient Canny's edge detection technique is used. The area borders in an image may become hazy due to inadequate lighting, leading to uncertainty in the gradient image. In order to deal with uncertainties, We have suggested a technique that repeatedly chooses the threshold values necessary for dividing the gradient in an images using the traditional Canny-edge detection method, based on concept of Type-2-fuzzy sets [25, 26]. Results show that our algorithm does a great job on a number of foggy images.

4. Experimental Results

The proposed technique is experimented on foggy images taken from Kaggle dataset [https://www.kaggle.com/datasets/aalborguniversity/aau-rainsnow]. Figure 2 shows results of the suggested technique on foggy/hazy images. The proposed technique is implemented during MATLAB R2020a (8.1.0.430) s/win 2.60Ghz CPU: Intel(R) Core (TM) i5-1035G1 @ 1.00GHz/1.19GHz CPU with 8Gb RAM machine. Table 1 contains the computed execution times for sample images. The finer borders of the images that were hidden in the hazy ones are retained in the reconstructed images. We note that the suggested method convincingly recovers by eliminating the delicate details of the substances that are present in the hazy image. The reconstructed output image has less brightness.



(a) Hazy images
(b) edge detected image
(b)de-hazed images

Figure 3: Sample dehazed images using proposed method

The results obtained are compared with the results obtained by applying methods of he.et.al [3] and ke.chen[24] in the literature. The results for sample images are presented in the Figure. 3 The Peak Signal to Noise Ratio or PSNR and the Structure Similarity Index Measure (SSIM) quality measures are applied to compare the effectiveness of the approaches.

The PSNR is mostly used in image compression to rate the quality of the rebuilt image. Typically, a greater PSNR would mean the reconstruction is of greater quality. PSNR is estimated using the following equation.

$$PSNR=10\log10\ (peakval2)/MSE$$

where peak value is the max value in the image intensity values and MSE represents mean square error.

According to SSIM, image degradation is defined as a variation in how structural information is perceived and highlights heavily interdependent or spatially confined pixels. The observed quality of images and videos is estimated by SSIM. The resemblance between the initially captured image and the restored image images is measured by SSIM, which is calculated by

$$SSIM(x,y)=[l(x,y)]^{\alpha}.[c(x,y)]^{\beta}.[s(x,y)]^{\gamma}$$

where l is the luminance, c is the contrast and s are the structure information and α, β, γ are the positive constants [26].

Table 1 below compares the results of the suggested procedures with those of alternative approaches in the literature in terms of execution time, PSNR and SSIM parameters. Figure 4 displays the values for PSNR and SSIM in a graphical form.

Table 1: Comparative analysis of the suggested approach with other methods

Method	Images					
		1	2	3	4	5
He[3]	TIME	1.14	1.61	1.13	1.25	1.13
	PSNR	20.18	20.74	19.48	18.59	20.30
	SSIM	0.83	0.80	0.77	0.81	0.79
Ke.Chen[24]	TIME	0.36	0.91	0.21	0.24	0.21
	PSNR	13.12	12.84	12.17	11.63	12.33
	SSIM	0.70	0.68	0.65	0.71	0.66
Proposed Algorithm	TIME	0.33	0.58	0.20	0.20	0.17
	PSNR	23.95	22.57	22.34	29.03	22.57
	SSIM	0.90	0.89	0.89	0.91	0.90

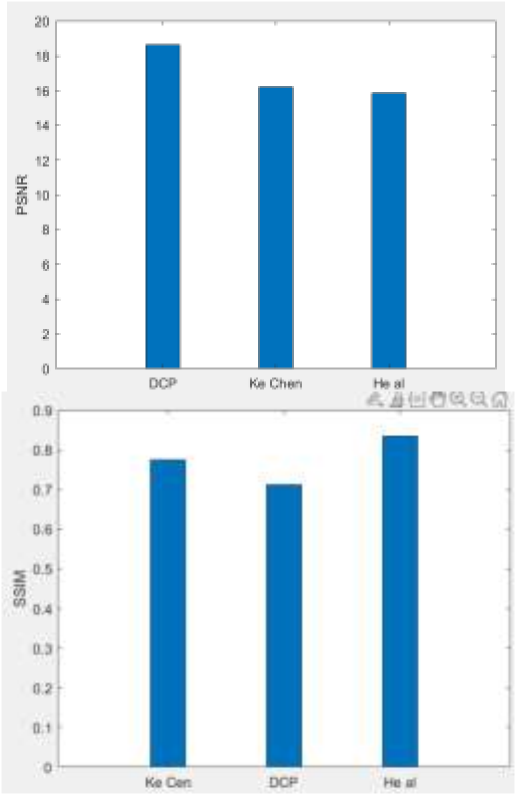


Figure 4: Comparison of methods on the basis of PSNR and SSIM quality parameters.

In comparison to the approaches in [3, 24], our algorithm obtains the fastest PC execution time. In most cases, our algorithm outperforms the alternative techniques in terms of haze removal visual outcomes.

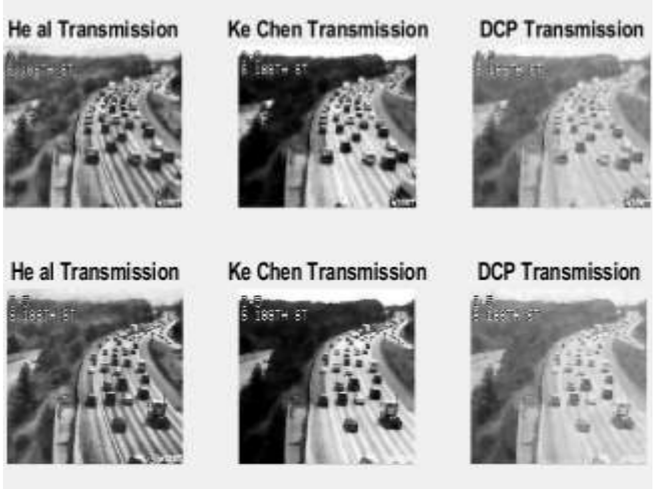


Figure 5: Results on transmission image

5. Conclusion

The fields of photography and image processing have experienced tremendous growth. The use of high-power lenses and electronic gadgets has greatly increased the quality of photos. However, due to atmospheric fog or snow affect the quality of the photos and movies. In this study, an improved technique for removing haze from photographs is proposed. In accordance with the dark-channel prior the technique for reducing haze is used by the system. When it is related to similar works our suggested technique in the literature maintains the highest image quality and also obtain images which haze free in the shortest amount of time. Figure 5 shown above showing the results of transmission image.

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