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Research Article

Restoration of Day and Night Foggy Images Using Fuzzy Based Dark Channel Prior

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Abstract: In this paper we proposed a fuzzy method based on dark channel prior to enhance the visibility of images that are degraded by fog or haze. In order to improve the perceptual visibility of RGB images, we modified the dark channel prior through fuzzy logic. The dark channel prior significantly measures the statistical estimation of haze-free outdoor images. It is based on fact that in haze free images most patches include pixels which have very low intensity in channel that is effective in estimation of thickness of haze and is capable to recover high quality haze-free images. We applied fuzzy logic with dark channel prior for computing probabilistic values other than lowest pixel intensity values among channels of images. Our experimental finding reveals that proposed method for restoration of foggy images using fuzzy logic along with atmospheric light, transmission map, and scene radiance effectively recovers the original fog free image. To further enhance the image perceptual quality, the guided filter was applied on the resultant fog free images for edge smoothing and noise removal. For performance evaluation of proposed method, we used Realistic Single Image De-hazing (RESIDE) dataset consisting of foggy images of different haze density. We introduce proposed scheme by combining the fuzzy logic with dark channel prior and demonstrate that the proposed method is capable to estimate the corresponding fog function which is significant for fog removal, improve image visibility, and increase user safety.

Keywords: Dark Channel Prior, Fuzzy Logic, Guided Filter, Transmission map, Air-Light, Realistic Single Image De-hazing (RESIDE).

1. INTRODUCTION

The exponential growths of the industrial sector in the last few decades have revolutionized our daily lives. However, we have also witness the rise of smog problem specifically in the industrial area around the globe that creates the problem of low visibility for air and land travellers. The reduction in light visibility and contrast has a significant impact on driver's safety as this can cause serious accidents that can ultimately cost human lives. Haze removal can produce depth information and promote several vision-based algorithms and advanced image editing tools [1-5]. However, removing haze from image is a challenging task due to its dependency on the unknown depth information. The area of haze detection and visibility estimation in foggy conditions has been heavily explored in research to improve the visibility of images with lower computational cost. N. S. Pal [6] proposed a simple technique for re-moving fog by using L_0 Gradient Minimization Filter to eliminate the halos but at the expense of higher computational cost. To overcome this limitation, Gu et al. [7] used the average saturated prior (ASP) technique to directly estimate the atmospheric scene and recover hazy images.

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This method is useful to reduce the computational cost; however, it requires complex mathematical computation, due to huge range of haze images. Histogram equalization [8] can also be used for contrast enhancement but due to flattering property the brightness of the image is changed. To resolve the issue of variation in brightness, a method based on bi-histogram equalization was proposed in [9, 10] to enhance the contrast of image without effecting the brightness. This approach has more computational cost as the bi-histogram completely depends on edge preserving filtering. Hussain used deep neural networks to recover scenes degraded by fog [11] for real time haze removal. However, this algorithm removes haze in few images and not works for some of the scenes clearly. A method based on integrating Principal Component Analysis (PCA), Multi-Scale Retinex (MSR) and Glob-al Histogram Equalization (GHE) was proposed in [12-13]. This method can efficiently eliminate the image degradation in foggy weather and improves image sharpness. A new optical model for hazy images was proposed [14] when light transmission distribution is unknown and non-convex value of transmission is converted into convex by estimation of atmospheric light. Further-more multilevel Haze wavelet is used for improvement of processing speed and exhibits the potential for real time application. This method is useful in haze removal but does not completely eliminate the haze. Moreover, the processing time depends on size of image presented for haze removal. To overcome this problem more advance technique was presented for de-hazing method by reducing retinex model [15]. This model utilizes two regularization terms for normalizing transmission map and scene radiance and provides satisfactory results, nevertheless still images values cannot be adjusted adaptively. Moreover, due to computational cost it cannot be applied on real time de-hazing application. HR-Dehazer method [16] is proposed in which encoder and decoder network is used for comparison of hazy images with clearer version image. After that a perceptual loss function is introduced for comparison between real and haze free image. This method outperforms on many datasets yet the metric used for generation of results may promote blurry results as compared to sharpness of images.

Defogging/dehazing solutions relying entirely on single images are suggested in [17,18]; however, they are not applicable for real time computer vision applications. In [19], dark channel prior (DCP) was introduced, in which we consider lowest intensity among the RGB channel to estimate the transmission in hazy images. Furthermore, Matting Laplacian matrix and a regularization parameter was used to estimate soft matting. The problem of this technique [19] is that it only removes the fog and is unable to enhance the contrast of the image. So there is a need for comprehensive and automated method for restoration of images that are degraded by fog and can overcome the drawbacks of the existing methods for real-time environment. Hence, we have merged fuzzy logic in dark channel prior method and obtained a better quality image with enhanced contrast. The process flow of Dark Channel Prior technique is presented in Fig. 1. The Dark Channel Prior is used to recover scene radiance with the estimation of Air-light and Transmission map. The air-light component depends on depth of scene which is the distance between object and the viewer. Thus, the air-light component should be smoothening and its value varies according to the scene depth. Due to varying of air-light component dark channel prior fails to perform equally on every image, as estimation of air light component is impossible in brighter regions. Therefore, there is a need to develop an effective and efficient method to use the fuzzy logic with dark channel prior in a simple manner to decrease the time constraint and improve the generalization of dark channel prior. To address these problems, we have used fuzzy logic [20] to provide more effective solution through exercising the fuzzy rules and fuzzy membership function. By this technique we can easily enhance the contrast of images and estimate the refined transmission map. The transmission maps are high quality image without colour distortion using membership value of each pixel of foggy image.

The main objective of this research work is to remove fog and to enhance the contrast of the image using fuzzy logic. Firstly, maximum of RGB channel is selected by fuzzy logic. The haze is estimated through the transmission map. For refinement, we have applied the scene radiance to obtain haze free image with enhanced contrast. The resultant image is then presented to the guided filter [21] for edge smoothening. Finally, we have obtained the de-hazed image with better contrast and preserved edges information. The entire process is shown in Fig 2. We have also developed a custom dataset of diverse hazy images for performance evaluation. Higher PSNR (peak signal-to-noise ratio) and Lower MSE a (mean square error) value indicates the effectiveness of our method in contrast state-of-the-art methods.

The rest of paper is organized as follows: Section 2 presents the methodology of the proposed method in detail. Section 3 provides a comprehensive discussion on the results obtained from the experiments. Section 4 presents the discussion related to proposed method results. Finally, Section 5 concludes the proposed method.

2. MATERIALS AND METHODS

In this paper we introduce the fuzzy logic based dark channel prior for fog removal. Our proposed membership functions of fuzzy logic performed inference to replace the maximum pixel value into the optimal representation across image channels. Then, this modified image is passed towards transmission map to estimate the thickness of haze. After fog removal we applied post processing operations using dark channel prior including light balancing, scene radiance and image sharping to enhance the perceptual information of image. The proposed dark channel prior based on fuzzy logic can be expressed mathematically as:

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

Where $J(\mathrm{x})$, (A) , $t(\mathrm{x})$ and f represents the image scene radiance, atmosphere light, the ratio of transmission and fuzzy logic respectively. The first component in the right-hand side of Eq. (1) $J(\mathrm{x})$ $t(\mathrm{x})$ is called direct attenuation which illustrates the scene radiance and its decay in the medium. Whereas, the second item A $(1\text{-}t(\mathrm{x}))$ is air light

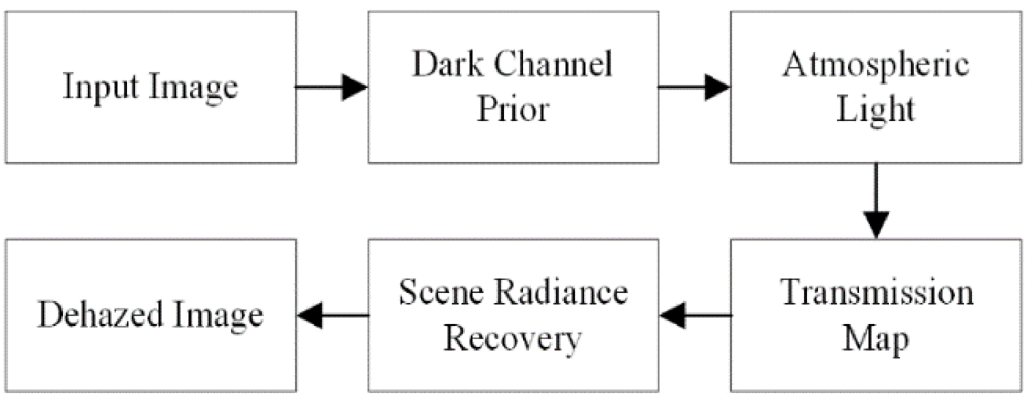

Fig. 1. Steps Involved in Dark Channel Prior

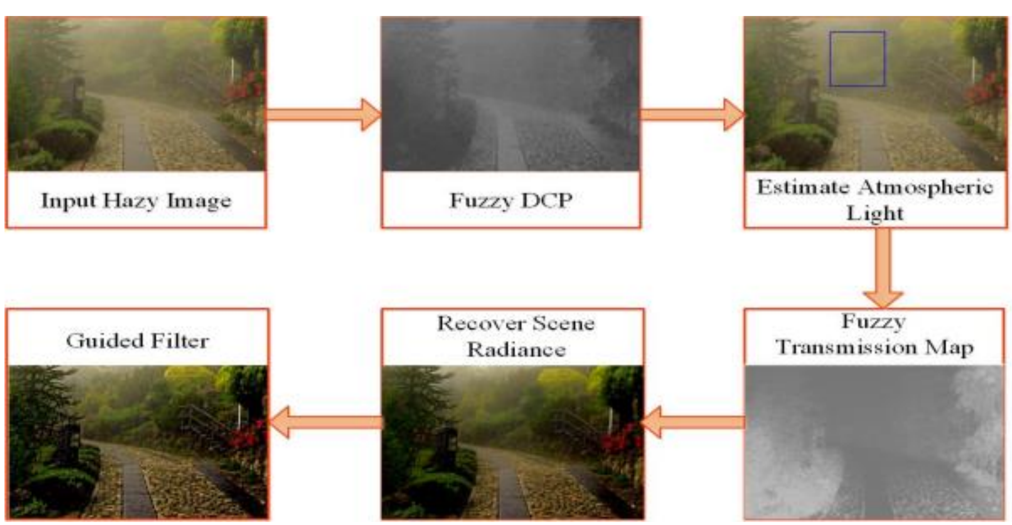

Fig. 2. Fuzzy Fog Removal Flow Chart.

component which results from the scattered light and leads to the colour shift of the scene.

2.1 Fuzzy Logic Based Dark Channel Prior

The dark channel prior assumes that most outdoor images consist of low intensity values in one of the RGB channel that do not exist in sky. We have selected these intensity values by applying the fuzzy logic on entire image as depicted in Fig 3. Scanning the image pixel by pixel is crucial task to obtain the output of dark channel prior. Therefore, we introduce sliding window operation in dark channel prior for identification of RGB values. Hence analysing the largest RGB values within sliding window is effective in image enhancement. The four directions chosen in 5x5 sliding window region is shown in Fig 4 to represent the pixel taking part in computation. Fuzzy theory introduced by Zadeh [22] is entirely based on human defined rules for fog removal. We designed fuzzy rules considering the human perceptual capabilities to perceive colours and inference the most suitable RGB value using fuzzy logic. We have extracted pixel value of each channel (Red, Green, and Blue) from the input image and then applied fuzzy rules on these RGB values for classification. Our main aim in this step is to classify the values of RGB within the range of 0-1 using the triangular membership function of fuzzy logic which is illustrated as follows:

$$Triangle(x,a,b,c) = \begin{cases} 0 & x \le a \\ \dfrac{x-a}{b-a} & a \le x \le b \\ \dfrac{c-x}{c-b} & b \le x \le c \\ 0 & c \le x \end{cases} \tag{2}$$

Where a and b represents lower and upper limits and c is the middle value obtained as a<c<b. The membership function of fuzzy logic is applied to transform the pixel values into fuzzy set during fuzzification and back to crisp set for de-fuzzification. Fuzzy set obtained during fuzzification is used to assign the value between 0 and 1 to image pixel. The crisp set obtained after defuzzification is used to convert the pixel value to 0 or 1 and to identify its belonging to relevant set as shown in Fig 5. A membership function is a curve that defines how each value in the input space is mapped between 0 and 1.

The resultant image obtained after application of fuzzy rules will be effective in distinguishing among the ambiguous colours of image and improve the perceptual quality of image. This entire process is depicted in Fig 6. The dark channel of outdoor scene using fuzzy system can be expressed as:

$$\mathrm{d}(j,i) = \mathrm{eval}\,f\mathrm{is}\ (\min(\mathrm{p}), f\mathrm{is}) \tag{3}$$

Where *d* and *p* represents dark channel and patch and evalfis selects minimum value from the image patch and pass these values to the fuzzy system that was created earlier and the resultant matrix of (m x n) will be stored in the dark channel (j, i) for further processing.

2.2 Transmission Map

After application of fuzzy rule, the resultant improved dark channelled prior image is passed to transmission map. Transmission map is used to detect the presence of haze thickness in an image as follows:

$$trans = 1 - w\left(\min_{y=\Omega(x)}\left(\min_{c}\frac{I^c(y)}{A^c}\right)\right) \tag{4}$$

If we remove haze completely from the image, then image seems unnatural. To keep natural effect of image some haze is sustained in the image. For this purpose, we introduced a constant w which is omega and set the value to 0.95. $\min_{y\in\Omega(x)}\left(\min_{c}\frac{I^c(y)}{A^c}\right)$ is the dark channel of normalized image . $\frac{I^c(y)}{A^c}$ Fig. 7(b) is the estimated transmission map of input image Fig 7(a).

2.3 Refinement Through Fuzzy Transmission

The fuzzy logic was further applied on image to refine the transmission map for noise removal and image enhancement. For this purpose, we proposed an adaptive directional fuzzy median filter and applied it on four major directions (horizontal, vertical and two diagonals) in a 5x5 sliding window.

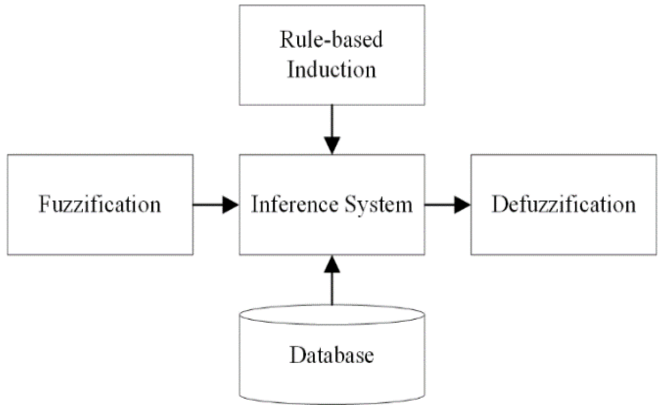

Fig. 3. Fuzzy Inference System for restoration of day and night foggy images

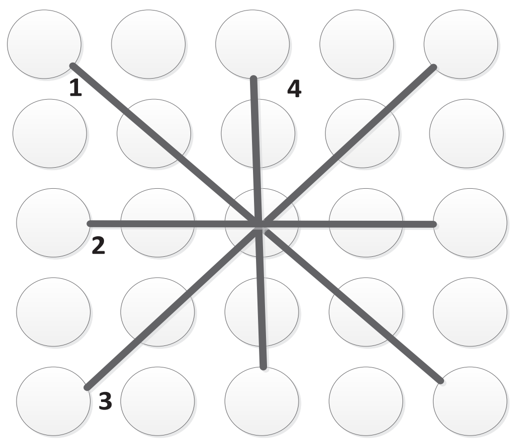

Fig. 4. 5x5 sliding window.

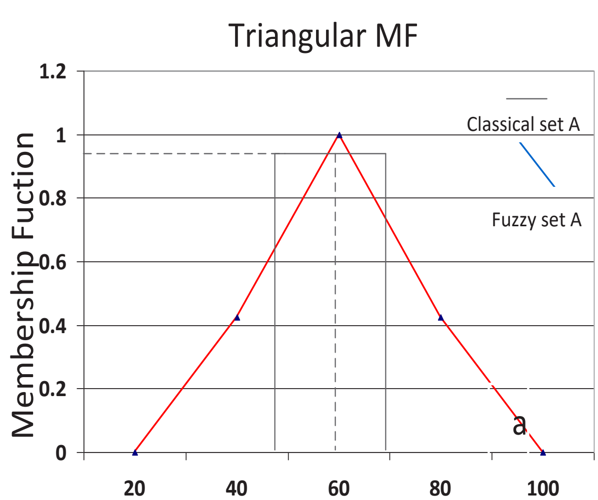

Fig. 5. Triangular membership function.

If centre pixel value is larger than the estimated threshold, then it is considered as a noisy pixel and values are replaced by 0. Whereas, in case centre pixel value is smaller than the threshold, then it is considered as noise free pixel whose values are replaced by 1. The coordinates of sliding window centred at specified location can be identified as:

$$\begin{aligned} D1 &= \{(i-2,j-2),(i-1,j-1),(i+1,j+1),(i+2,j+2)\} \\ D2 &= \{(i,j-2),(i,j-1),(i,j+1),(i,j+2)\} \\ D3 &= \{(i+2,j-2),(i+1,j-1),(i-1,j+1),(i-2,j+2)\} \\ D4 &= \{(i-2,j),(i-1,j),(i+1,j),(i+2,j)\} \end{aligned} \quad (5)$$

To differentiate between the noisy and edge pixels, we have computed the absolute difference as follows:

$$D(i+k,j+l) = Trans\_est(i+k,j+l) - Trans\_est(i,j) \quad (6)$$

Where $i+k, j+l \neq (i,j)$, the minimum value is deter-mined as:

$$D_{\min} = \max(D) \quad (7)$$

The maximum operator was selected to set the noisy pixels detected earlier as 255 and noise free pixels as 0. In contrast, minimum operator was not suitable for identification of noisy and noise free pixels due to the fact that entire image becomes black, therefore we suggested to use maximum operator, as demonstrated in Fig 8. Fuzzy filtering is applied to the extracted information stated in Eq. (6). The threshold values were selected as 10 and 30 because we obtained the best results on these values during experimentation. At the end we have restored the detected noisy pixels as follows:

$$Y(i,j) = 1 - Fuzzy(i,j).image(i,j) + Fuzzy(i,j).Median(i,j) \quad (8)$$

2.4 Atmospheric Light Balancing

Most of the existing de-hazing methods consider the pixels with highest intensity values as atmospheric light. However, it is challenging to identify pixels representing atmospheric light as this approach misclassifies the pixels of white objects as those of atmospheric light. To overcome this issue, we used the dark channel prior (DCP) technique to estimate the atmospheric light. At first, we identified 0.1% brightest pixels through the CP as shown in Fig 9(a) with black border. From these pixels, the highest pixels were selected as atmospheric light (A) which is shown with black border in Fig 9(b). The black pixel demonstrates the collection (brightest pixels to dark channel) of pixels; the algorithm discovers the max R, G, and B values to approximate the atmospheric light.

2.5 Scene Radiance

We can improve the scene radiance $J(x)$ by using the transmission map as shown in Eq. (1). However, when the transmission map t(x) is closer to zero then the direct attenuation i.e. J(x)t(x) become zero which is prone to noise. Therefore, we have limited t(x) to a lower bound t0, which preserves certain amount of haze in the dense haze region. The final scene radiance J(x) is recovered using Eq. (9) as shown in Fig 7(c).

$$J(x) = \frac{I(x) - Atmos}{\max(t(x), t0)} + Atmos \quad (9)$$

The lower bound t0 is estimated to be 0.1 and usually increases when an image contains more portions of sky pixels; otherwise the sky region is neglected as artefacts. Then, the improved image is passed to guided filter for image sharpening.

2.6 Guided Filter

We have applied the guided filter [23] to sharpen the edges in the resultant image. The guided, filtering input images can be symbolized as G, D respectively. The guided filter is represented as:

$$G_i = a_k I(x) + b_k, \forall i \in w_k \quad (10)$$

Where I(x) represents the image and k is the index of a 3x3 box filter applied on the image. ak and bk are computed as:

$$a_k = \frac{\frac{1}{w}\sum_{i \in w_k} I_x D_i - \mu_k \overline{D_k}}{\sigma_k^2 + \varepsilon} \quad (11)$$

$$b_k = \overline{D_k} - a_k \mu_k \quad (12)$$

Where μ_k and σ_k^2 are the mean and variance of image I. In the next phase, the filtered image is

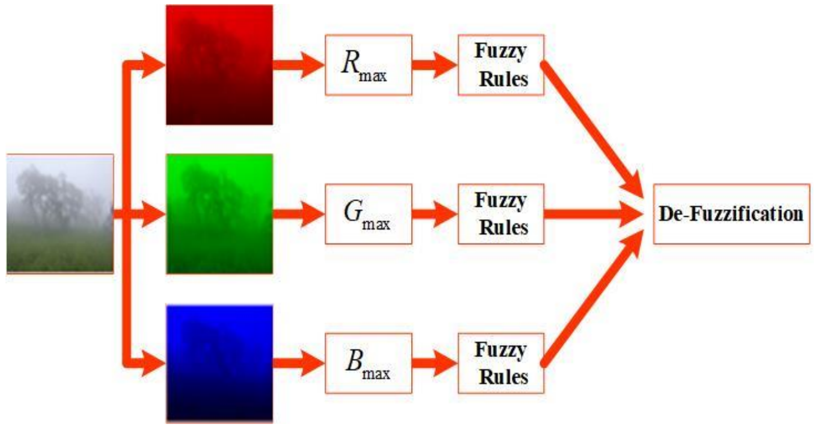

Fig. 6. Fuzzy logic for RGB classification.

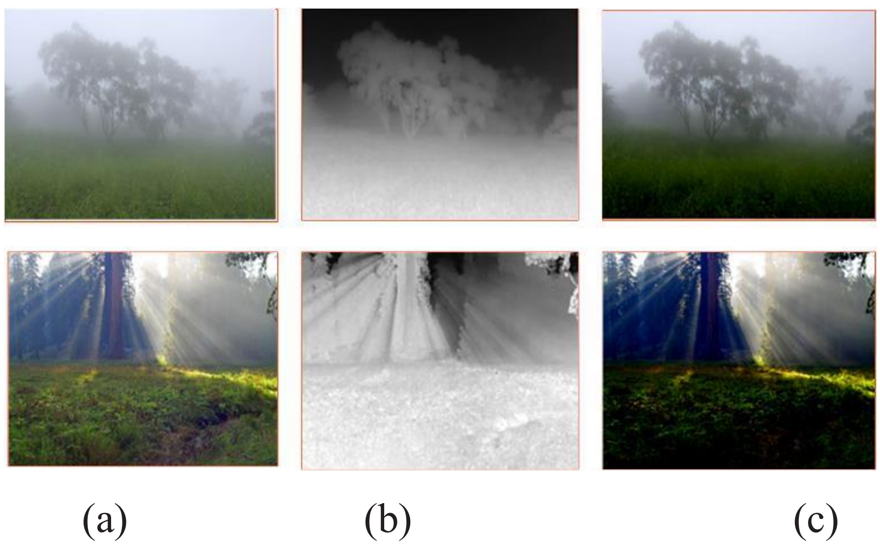

Fig. 7. (a) Original Image (b) Transmission Map (c) Scene Radiance

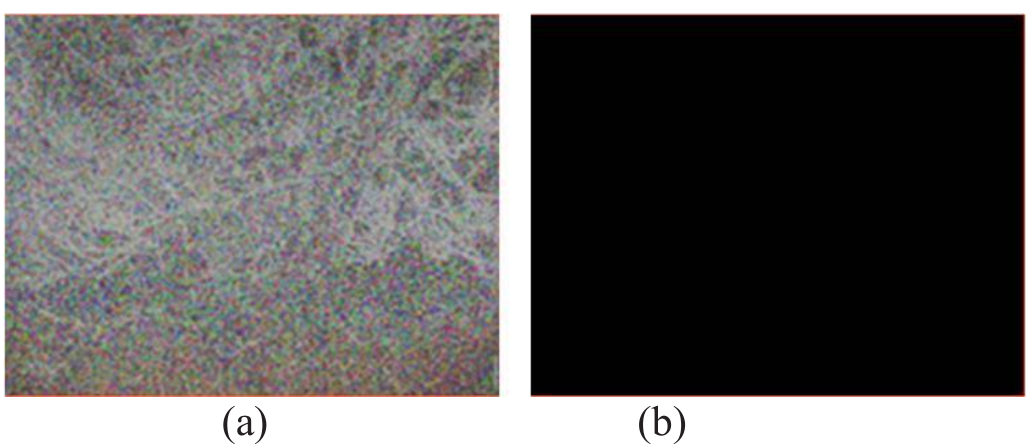

Fig. 8. Local information extracted using (a) maximum operator and (b) minimum operator.

(a)

(b)

Fig. 9. (a) 0.1% brightest pixel is marked in black, (b) Highest intensity pixels are considered as atmospheric light.

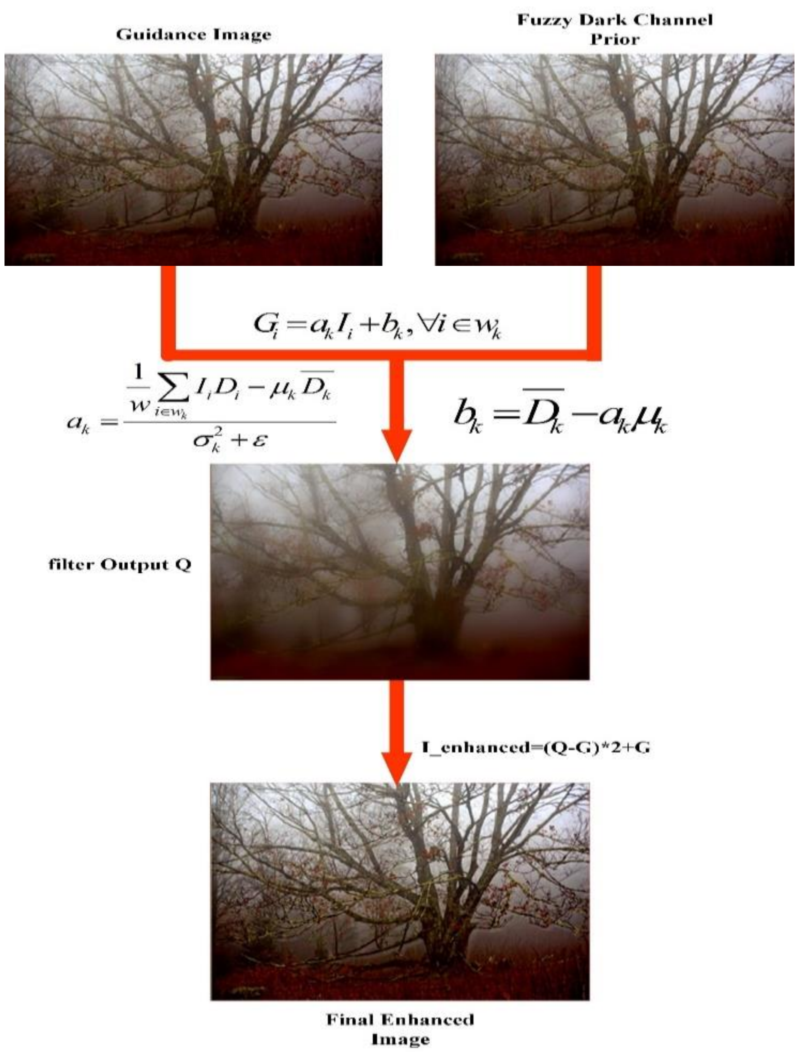

Fig. 10. Resultant enhanced image obtained after guidance Filter.

further refined to obtain the enhanced image with preserved edges as follows:

$$\bar{I}_E = (D - G) * 2 + G \quad (13)$$

Where D and G represents the image obtained after applying the fuzzy fog removal technique and guided filter respectively. For simplicity, we have assumed input and guided images to be similar. The process of obtaining the enhanced image is presented in Fig 10.

3. RESULTS AND DISCUSSION

3.1 Datasets and Experimental Setup

This section presents the comprehensive discussion on the experiments performed to measure the performance of proposed method. Realistic Single Image De-hazing (RESIDE) dataset [29] was selected for evaluation which consists of variety of thick and thin fog density images. These subsets of images were used in evaluating performance of our presented method. These images are in JPEG format of 800 x 500 dimensions. The MATLABR, R2017A platform was used for simulation of proposed technique.

3.2 Evaluation Measures

For performance evaluation, we have used the metrics of MSE and PSNR. PSNR is used for comparison of image quality between original and restored image. Higher value of PSNR indicates better restored image and vice versa. For MSE, lower value indicates better restored image and vice versa. We computed the MSE and PSNR as follows:

$$MSE = \frac{1}{MxN} \sum_{i}^{m} \sum_{j}^{n} | O_{i,j} - R_{i,j} |^2 \quad (14)$$

$$PNSR = 10 \times \log 10 \times I^2 \left(\frac{1}{MSE} \right) \quad (15)$$

Where Oi,j is the original image and Ri,j is the restored image of size m x n. I represent the maximum intensity of an image.

3.3 Experimental Results

The PSNR and MSE values of the restored images obtained for the proposed method is provided in Table 1. It can be observed from Table 1 that the proposed method is very effective in terms of restoring images corrupted by the fog. An average PSNR value obtained is 61.89 Db as a result of

Table 1. MSE and PSNR values.

Images	Image Size	MSE	PSNR
Image 1	743x521	0.052	60.924
Image 2	852x480	0.077	59.252
Image 3	754x440	0.154	56.232
Image 4	900x600	0.075	59.36
Image 5	800x505	0.0015	76.458
Image 6	918x752	0.079	59.139
Average		**0.073**	**61.89**

Table 2. Analysis of PSNR with Different Techniques.

Images	DehazeNet	HR-Dehazer	DCP	Proposed Method
Fig 1	70.675	55.12	61.584	60.924
Fig 2	63.301	70.634	57.022	59.252
Fig 3	58.147	65.241	57.693	56.232
Fig 4	63.072	53.487	58.966	59.36
Fig 5	65.876	62.127	59.585	76.458
Fig 6	64.124	60.920	59.618	59.139
Average	**64.199**	**61.254**	**59.07**	**61.89**

Fig. 11. Experimental results of de-hazing method (a) Original image (b) De-haze-Net [24], (c) HR-De-hazer [16], (d) DCP method [19], (e) the proposed method.

Table 3. Analysis of MSE with Different Techniques.

Images	DehazeNet	HR-Dehazer	DCP	Proposed Method
Fig 1	0.005	0.152	0.045	0.052
Fig 2	0.034	0.077	0.129	0.077
Fig 3	0.099	0.154	0.110	0.154
Fig 4	0.042	0.075	0.082	0.075
Fig 5	0.017	0.152	0.071	0.001
Fig 6	0.026	0.077	0.070	0.079
Average	**0.075**	**0.092**	**0.085**	**0.073**

processing multiple images. In contrast 0.073 MSE value is obtained. Greater value of PSNR and smaller value of MSE concluded that our proposed method is better in evaluating information and producing less error. Due to addition of fuzzy logic technique along with guided filter hazy images are easily recovered more precisely with less computational time as compared to other techniques.

3.4 Performance Comparison

In this experiment, we have compared the performance of the proposed method with existing state-of-the-art de-hazing methods [16,19,24] for image restoration. The fog removal experimental results on outdoor images are shown in Fig11 where the proposed method performs superior without color distortion as compared to existing methods [16,19,24] due to modified dark channel prior method based on fuzzy logic.

In DCP method [19], fog was removed however this method is unable to enhance the contrast of the images. In addition, DCP method is also unable to predict fog in brighter regions of an image. The proposed method provides better results with enhanced contrast as compared to DCP method. Dehaze-Net method [24] considers only specified area of image and fails to remove the fog from the image completely. Likewise, DCP method, Dehaze-Net is also unable to enhance the contrast of an image. In Fig 11 (c) and (d), we can observe that the images contain the bluish effect due to degradation of atmospheric light. These images are also unable to preserve the edges. Fig 11 (e) shows oversaturated and over enhanced images due to incorrect estimation of brightest pixels. Therefore, accurate estimation of atmospheric light is essential in preserving the quality of image. In the proposed algorithm, both sky and road region provides better results without color distortion or over saturation. In HR-Dehazer [16] original colors of image are mixed with fog removal technique hence image is impossible to identify.

The comparative analysis of the proposed and other approaches [16,19,24] based on PSNR are presented in

Table 2. The proposed method achieves an average PSNR of 61.89 as compared to 64.199, 61.254 and 59.07 obtained in Dehaze-Net [24], HR-dehazer [16], DCP method [19] respectively on the similar dataset. Higher PSNR value achieved by our method indicates the significance of the proposed method in terms of de-hazing foggy images in contrast of existing methods.

We obtained the improved results because of using background as well as foreground information in 5x5 sliding window to restore the corrupted pixels. Most often noise removal technique disturbs the original pixel values in detailed region and hence thin lines and texture regions cannot be protected in the image. We have applied the directional median filter to preserve the edges besides smoothing the images hence, we obtained better quality restored images after de-hazing. Similarly, Table 3 presents a comparative analysis of the proposed method with the existing approaches based on MSE. Our method provides an average MSE of 0.073 obtained during the experimentation. Whereas, Dehaze-Net [24], HR-dehazer [16], DCP [19] methods provide MSE of 0.075, 0.092 and 0.085 respectively. The lower MSE value of 0.073 signifies that the proposed method performs better as compared to existing methods [16, 19, 24].

4. DISCUSSION

The time complexity of our method is lower as compared to other techniques and doesn't depend on size of the image. Average PSNR value of our method is higher as compared to other methods. The lower values of PSNR represents greater information is loss after image dehazing. Due to involvement of fuzzy logic along with guided filter we have obtained low MSE and higher PSNR value as a result less information is lost and error rate is also lower. The processing speed of other approaches [16,19,24] completely depends on size of image which results in loss of information and increase error rate. As a result, we concluded that our methods can be beneficial for real time fog removing application.

5. REFERENCES

1. H. Wei., Y. Wang, and A. Wang. A high fidelity haze removal algorithm for optical satellite images using progressive transmission estimation based on the dark channel prior. *International Journal of Remote Sensing,* 40(9) 3486-3503 (2018).

2. Y. Wang., F. Fangfa., L. Fengchang., X. Weizhe., S. Jinjin, and J. Wang. Haze removal algorithm based on single-images with chromatic properties. *Signal Processing: Image Communication* (2018).
3. Y. Liang., Z. Kuibin., Z. Wenqiang, and Y. Li. Research on single image haze removal algorithm based on parameter optimization search of linear model. *IEEE,International Conference on Advanced Mechatronic Systems* (ICAMechS): 326-331 (2018).
4. L. Jimin., Y. Wang, and S. Zhou. Haze Removal Algorithm Using Color Attenuation Prior and Guided Filter. *In Proceedings of the 3rd International Conference on Multimedia Systems and Signal Processing,* ACM: 41-45 (2018).
5. Yuan, and H. Huang. Image Haze Removal via Reference Retrieval and Scene Prior. *IEEE Transactions on Image Processing* 27: 4395-4409 : doi: 10.1109/TIP.283790 (2018).
6. N.S. Pal., S. Lal, and K. Shinghal. A Visibility Restoration Framework for rainy images by using Lo gradient minimization and Bilateral Filtering. *International Conference on Advances in Computing, Communication Control and Networking* (ICACCCN) : 848-852 (2018).
7. G. Zhenfei., J. Mingye, and Z. Deng-yin. A Single Image Dehazing Method Using Average Saturation Prior. *Mathematical Problems in Engineering* : 1-17 (2017).
8. W. Jinbao., K. Lu, J. Xue., N. He, and L. Shao. Single image dehazing based on the physical model and MSRCR algorithm. *IEEE Transactions on Circuits and Systems for Video Technology* 28: 2190-2199 (2018).
9. K. Jin-Hwan., J.Y. Sim, and C.S. Kim. Single image dehazing based on contrast enhancement. *In Acoustics, Speech and Signal Processing (ICASSP), IEEE International Conference on*: 1273-1276 (2011).
10. P. Mario., H. Belzner., G. Rigoll, and S. Ilić. Image based fog detection in vehicles. *In Intelligent Vehicles Symposium* (IV): 1132-1137 (2012).
11. H. Farhan, and J. Jeong. Visibility enhancement of scene images degraded by foggy weather conditions with deep neural networks. *Journal of Sensors* (2016).
12. B. Yu., B.S. Kim, and K.H. Lee. Visibility Enhancement Based Real--Time Retinex for Diverse Environments. *In Signal Image Technology and Internet Based Systems (SITIS), Eighth International Conference on*: 72-79 (2012).
13. E. Salari., M. Li, and D. Ouyang. Foggy image enhancement based on Principal Component Analysis. *In Circuits and Systems (MWSCAS), IEEE 56th International Midwest Symposium on:* 1259-1262 (2013).
14. L. He., C. Zhang, R. Yang, and K. Zhu. Convex optimization for fast image dehazing. *IEEE International Conference on Image Processing (ICIP), Phoenix,* AZ, 2246-2250: doi: 10.1109/ICIP.7532758(2016).
15. Y. Liu., J. Shang, L. Pan, A. Wang, and M. Wang. A Unified Variational Model for Single Image Dehazing. *in IEEE Access* 7: 15722-15736: doi: 10.1109/ACCESS.2894525 (2019).
16. S. Bianco., L. Celona., F. Piccoli, and R. Schettini. High-Resolution Single Image Dehazing using Encoder-Decoder Architecture. *In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops* (2019).
17. Q. Liu., X. Gao, L. He, and W. Lu. Single Image Dehazing With Depth-Aware Non-Local Total Variation Regularization. *IEEE Transactions on Image Processing* 27: 5178-5191 (2018).
18. A.O. Ancuti., C. Ancuti, and P. Bekaert. Effective single image dehazing by fusion. *IEEE International Conference on Image Processing*, Hong Kong, 3541-3544 (2010).
19. H. Kaiming., J. Sun, and X. Tang. Single image haze removal using dark channel prior. *IEEE transactions on pattern analysis and machine intelligence* 33: 2341-2353 (2011).
20. H. Muhammad., A. Hussain, and T.S. Choi. Adaptive threshold based fuzzy directional filter design using background information. *Applied soft computing* 29: 471-478 (2015).
21. K. Fei., W. Chen., C. Wen, and Z. Li. Gradient domain guided image filtering. *IEEE Transactions on Image Processing* 24: 4528-4539 (2015).
22. Lotfi. Z.A. Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic. *Fuzzy sets and systems* 90, p. 111-127 (1997).
23. H. Kaiming., J. Sun, and X. Tang. Guided image filtering. I*n European conference on computer vision*, Springer, Berlin, Heidelberg, 1-14 (2010).
24. B. Cai., X. Xu, K. Jia, C. Qing, and D. Tao. DehazeNet: An End-to-End System for Single Image Haze Removal. *IEEE Transactions on Image Processing* 25: 5187-5198 (2016).
25. P. Luo., R. Chunwang., K. Jian,and Q. Zheng. Improvement of the Algorithm Based on Dark Channel Prior Defogging. IOP Conference Series. *Earth and Environmental Science*. 300: doi:10.1088/1755-1315/300/2/022045 (2019).

26. Y.T. Peng., C. Keming, and C. Pamela. Generalization of the Dark Channel Prior for Single Image Restoration. *IEEE Transactions on Image Processing,* 1-1: doi: 10.1109/TIP.2813092 (2019).
27. W. Wencheng., Y. Xiaohui., W. Xiaojin, and L. Yunlong. Fast Image Dehazing Method Based on Linear Transformation. *IEEE Transactions on Multimedia,* 1-1: doi: 10.1109/TMM.2652069 (2017).
28. M. Everingham., L.V. Gool., C.K.I. Williams, J. Winn, and A. Zisserman. The pascal visual object classes (voc) challenge. *International Journal of Computer Vision,* 88(2):303– 338 (2010).
29. L. Boyi., W. Ren., D. Fu., D. Tao, and D. Feng. Benchmarking Single Image Dehazing and Beyond. *IEEE Transactions on Image Processing* 28: 492-