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A Hybrid Defogging Technique based on Anisotropic Diffusion and IDCP using Guided Filter

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Abstract

In poor weather condition, fog removal from an image is an unavoidable problem. Various methods have been proposed in literature for de-hazing of image based on Dark Channel Prior (DCP) such as Improved Dark Channel Prior (IDCP), Anisotropic Diffusion and IDCP method using Guided Filter. This paper provides a hybrid strategy based on IDCP using Guided Filter and Anisotropic Diffusion method. The former strategy is used for estimating and refining transmission map while the later is used to estimate and refine airlight. In addition, this paper compares the above mentioned techniques using several performance metrics such as Normalized Color difference (NCD), Color Naturalness Index (CNI) and number of saturated pixel. The results shows that the visual quality of our hybrid approach is much better as well as the performance metrics mentioned above optimizes to a great extent.

Keywords: *Dark channel, Atmospheric light, Transmission map*

1. Introduction

Bad weather conditions such as fog and haze [1, 2, 20, 21] degrades our image quality due to presence of substantial particles in the atmosphere which have significant size [3] between 1-10 μm. The light coming from a camera is absorbed and scattered by these atmospheric particles due to which the visibility of the scene is blemished. This invisibility is caused by two fundamental phenomenon's: Direct attenuation [1, 6] and Airlight [1, 6]. Fog is the combination of both of these phenomenons.

$$Fog = Direct\ attenuation + Airlight$$

Direct Attenuation: Light coming from a view point gets attenuated because of scattering by atmospheric particles. This phenomenon is termed as direct attenuation which reduces contrast of the scene. It is the function of the distance between camera and object. It describes scene radiance and decay in the medium. It is a multiplicative distortion of the scene radiance. Direct attenuation is given by equation (1) as:

$$Direct\ attenuation = J(x)t(x) \tag{1}$$

Where J(x) is scene radiance and t(x) is transmission map (see equation (2)):

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

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As we can see in equation (2), transmission map decreases exponentially with the depth d(x). If we accurately estimate the transmission map, we are able to recover the depth of an object in an image to a certain extent.

Where β is atmospheric attenuation coefficient, d(x) is the distance between an object and observer.

Airlight: Light coming from the source is scattered towards camera and adds whiteness in the image, this phenomenon is termed as airlight and is also the function of the distance between camera and object. It results from the previously scattered light and leads to the shift of the image colors. It is the additive distortion of the scene radiance. Airlight can be given by equation (3) as:

$$Airlight = A * (1 - t(x)) \tag{3}$$

Where A represents the global atmospheric light and t(x) is transmission map. Now, the model widely describes the formulation of foggy image is given by equation (4) follows [1, 2, 5, 6]:

$$I(x) = J(x)t(x) + A * (1 - t(x)) \tag{4}$$

Where, I(x) represent the intensity of x^{th} pixel of an image. To show the impact of fog on images, let us take an image and introduce artificial fog in that image as shown in Figure 1.

(a) Original image (b) Foggy image

Figure 1. Impact of Fog

Figure 1(a) represents the original image while Figure 1(b) represents the foggy image. It is quite clear from the Figure. 1, to recover the original image, we have to reduce the effect of haze or fog from the image. Various defogging techniques [7-14] have been proposed based on dark channel prior technique.

The first technique among these being proposed by He *et al.* Though this method provided good recovery of foggy images but it suffers from its inability to refine the sky region & airlight in addition to producing halo effects. Therefore, IDCP method was proposed which was an improvement of DCP. The method provided good results not only for non-sky regions but at the same time filter out the substantial sky regions. To refine airlight and contrast of the scene, Anisotropic Diffusion technique was proposed by A. K. Tripathi *et al.* in order to eliminate the halo effect from image, IDCP using Guided Filter was proposed. This method refines the transmission map using guided filter to a great extent. Thus, it is quite clear from the above discussion that if a hybrid strategy that combines IDCP using guided filter and Anisotropic Diffusion method is proposed will provide fruitful result. This paper provides the same.

The rest of the paper is organized as follows. Section 2, describes the various fog removal techniques. The proposed algorithm is described in Section 3. Section 4, contains simulation setup parameter. Section 5, shows the experimental results and we draw our conclusion in the last section.

2. Literature Survey

In this section, various fog removal techniques [7, 8, 11, 12, 14] have been discussed that uses a single image to remove fog (see Figure 2)).

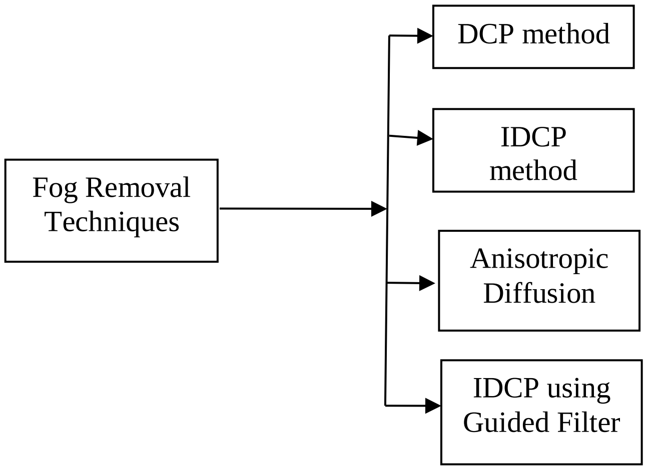


Figure 2. Various Fog Removal Techniques

The detailed explanation of each technique is as follows:

2.1. Dark Channel Prior (DCP):

Fog from an image is removed by using a single image fog removal method. The most predominant method [7-8] is DCP method. It estimates both transmission map as well as airlight to recuperate the original image from foggy image.

Dark Channel Creation: For creation of dark channel, it uses lowest intensity pixel of a patch of different size in three color planes namely R, G, B. For an arbitrary image J, its dark channel is given by equation :

$$J_{dark}(x) = min_{c\in}\{r, g, b\}\left(min_{y\in p(x)}\left(J_c(y)\right)\right) \quad (5)$$

Where J^c is a color channel of J and p(x) is a local patch centered at x. A dark channel is the outcome of two minimum operators.
Block Diagram of DCP is shown in Figure 3:

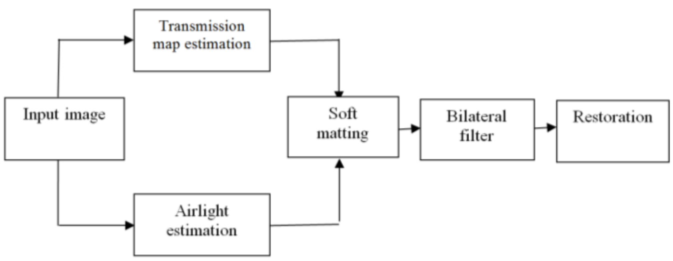


Figure 3. Block Diagram of DCP

Detail explanation of each block is as follows:

Transmission Map Estimation: Firstly, haze image equation which is given by equation (3) is normalized by A as follows:

$$\frac{I^c(x)}{A^c} = \frac{t(x)J^c(x)}{A^c} + (1 - t(x)) \tag{6}$$

Where $I^c(x)$ is the intensity of foggy image I of x^{th} pixel; t(x) is transmission map; $J^c(x)$ is scene radiance of haze free image; and A is global atmospheric light. From equation (), we observed that the dark channel of an image is close to zero. Since, A is some positive quantity.

$$J^{dark}(x) = min_{c\in\{r,g,b\}}\left(min_{y\in p(x)}\left(J^c(y)\right)\right) = 0 \tag{7}$$

As t(x) is constant in a patch. Therefore, we rewrite the equation (6) for estimation of transmission map [6] as:

$$\acute{t}(x) = 1 - min_{y\in p(x)}\left(min_c\left(\frac{I^c(x)}{A^c}\right)\right) \tag{8}$$

We keep some amount of haze in an image by adding a factor called w (0<w≤1) so that image looks natural. Hence, the new estimated transmission map is given by equation (9):

$$\check{t}(x) = 1 - w * min_{y\in p(x)}\left(min_c\left(\frac{I^c(x)}{A^c}\right)\right) \tag{9}$$

For refinement of transmission map, we used soft matting techniques and bilateral filter.

Soft Matting: The haze image equation which given by equation (4) is similar to image matting [9] equation (10)

$$I(x) = F\alpha + B(1 - \alpha) \tag{10}$$

Where F and B are foreground and background colors respectively and α is foreground opacity which is exactly similar to transmission map in haze image equation.
Now, refined transmission map is denoted by $\tilde{t}$(x) and Rewriting t(x) and t'(x) in their vector forms as t and t', to minimize the cost function given by equation (11):

$$E(y) = t^T Lt + \lambda(t - \tilde{t})^T(t - \tilde{t}) \tag{11}$$

Here, first term represents the smoothness and second represents the data term having weight λ. L denotes the laplacian [6] matrix whose elements are defined by equation (12):

$$\sum_{k|(i,j)\in w_k}\left(\delta_{ij} - \frac{1}{|w_k|}\left(1 + (I_i - \mu_k)^T\left(\Sigma_k + \frac{\varepsilon}{|w_k|}U_3\right)^{-1}(I_j - \mu_k)\right)\right) \tag{12}$$

Here, I_i and I_j are the colors of the input image I at pixels i and j, δ_{ij} is the Kronecker delta, μ_k and Σ_k are the mean and covariance matrix of the colors in window wk, U_3 is a 3×3 identity matrix, Ɛ is a regularizing parameter, and $|w_k|$ is the number of pixels in the window w_k.

The optimal t can be obtained by solving the following sparse linear system as given by equation (13):

$$(L + \lambda U)t = \lambda t' \quad (13)$$

Bilateral Filter: The purpose of applying bilateral filter [10] is to preserve the edges of an image.

Airlight Estimation: We pick the top 0.1 % brightest pixel of dark channel prior and among these pixels, the pixel with highest intensity in input hazzy image I is considered as airlight [1].

Restoration: Finally, Image is recuperated using the equation (14) given below:

$$J(x) = \frac{(I(x) - A)}{(max(t(x), t_o))} + A \quad (14)$$

Where t_0 represents the lower transmission limit and in our experiment we take its value 0.1

Advantage:

- Single image is used for restoration of foggy image.
- Transmission map is estimated accurately.

Disadvantage:

- Various assumptions have to be made for estimation of airlight.
- It may be invalid when scene object is intrinsically similar to airlight (snowy ground).
- It produces Halo effects in the region of discontinuous depth.
- The transmission map estimated is refined using soft matting technique which increases the time complexity.

2.2. Improved Dark Channel Prior (IDCP)

Yan Wang and Bo Wu proposed an algorithm called Improved Dark Channel prior [11], which is based on dark channel concept to estimate the atmospheric light and obtain better results. It further resolves the problem of significant region which contains sky. Bock diagram of IDCP is as shown in Figure 3:

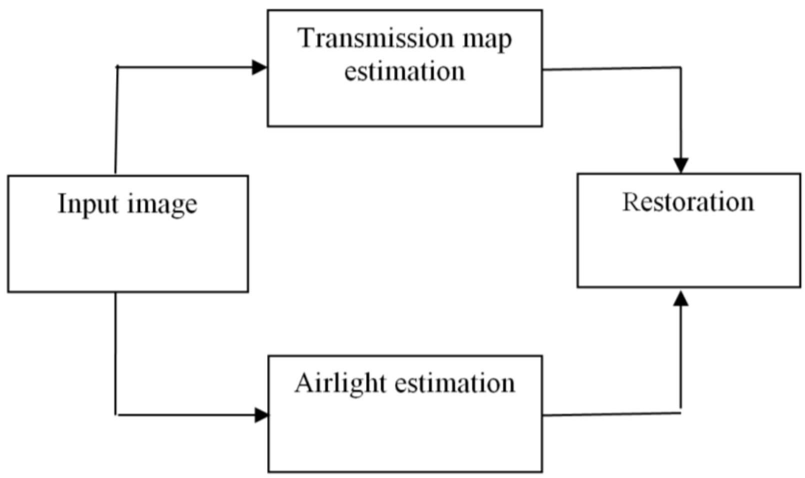


Figure 3. Block Diagram of IDCP

The detailed explanation of each block is as given below:

Dark Channel Creation & Transmission Map Estimation: IDCP created dark channel in the same way as created by DCP mentioned above.

Transmission Map Estimation: Transmission map is estimated using equation 6-9 mentioned above in the DCP. IDCP doesn't employ any soft matting technique for refinement of transmission map since it is very time consuming step.

Airlight Estimation: Atmospheric light will be properly estimated among the pixels which contain thick haze, if we increase the size of the window to 31, because min filtering over small window size can corrupt our image. To find the maximum R, G, B values which resemble the atmospheric light, a group of brightest pixels belonging to dark channel is estimated using this algorithm. It may be estimated by 2 methods:

i. Find a region which appears to be farthest from the camera and use the rectangle window to select that region.
ii. To estimate atmospheric light, compute the dark channel in rectangular region.

Image Restoration: Image is recuperated using the equation (14) given above. In IDCP method, the lower limit of transmission map is increased from 0.1 to 0.35, to remove the significant sky region so that sky region looks smoother and brighter.

Advantage:
- The atmospheric light is properly estimated by increasing window size to 31.
- Time complexity is reduced because it doesn't make use of soft matting technique.
- The significant sky region becomes brighter and smoother.

Disadvantage:
- It produces Halo effects in the region of discontinuous depth.
- It can't estimate the transmission map accurately.

2.3. IDCP using Guided Filter

IDCP using Guided Filter was proposed to overcome the defects of DCP and IDCP i.e. they produces halo effects. To solve this problem, atmospheric light is estimated by [12] based on the imaging law of densest hazy regions and transmission map is refined using guided filter [13]. The block diagram of IDCP based on guided filter is shown by Figure 5 as:

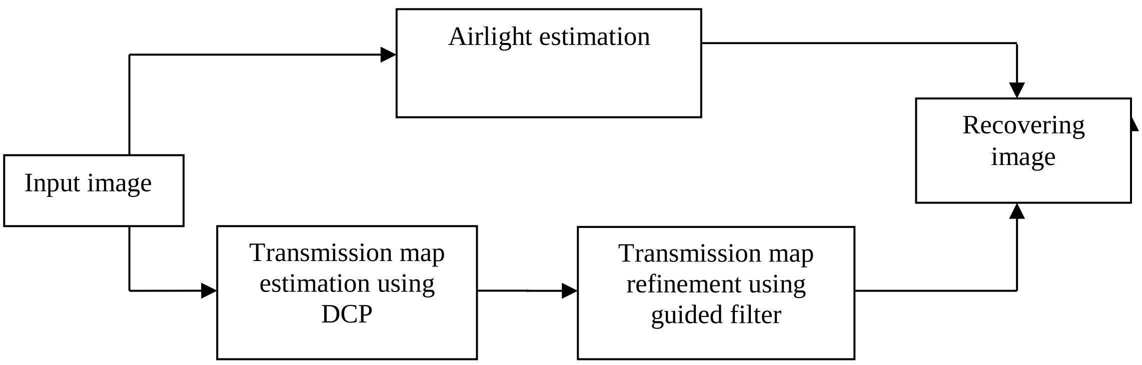


Figure 5. Block Diagram of IDCP Using Guided Filter

The detail explanation of each block is given below:

Dark Channel: IDCP using Guided Filter uses the same concept for creation of dark channel as stated by DCP.

Transmission Map: To properly estimate transmission map, a reduction mechanism is purposed which is given by equation (15):

$$t'(x,y) = \begin{cases} 1, f(x,y) < \sigma \text{ and } I(dark)(x,y) > \mu \\ \bar{t}(x,y) \end{cases} \quad (15)$$

Where, f(x, y) represents the deviation map which is given by:

$$f(x,y) = max_{c\in(R,G,B)} I^c(x,y) - min_{c\in(R,G,B)} I^c(x,y) < \alpha \quad (16)$$

Here, α and σ are constant parameters whose value is in between 2-5 and 4-10 respectively.μ is called the judgment threshold and is calculated by OTSU method
$\bar{t}(x)$ is same as given by equation (9) of DCP method.

But the transmission map obtained by equation (15) needs to be refined because it is constant in a patch and contains halo effect. Hence, to remove halo effect, guided filter is used which is edge preserving operator.
Guided Filter [13] operation is defined by equation (17) given below:

$$t(i) = 1/N \sum_{k:i\epsilon w_k} a_k I_i + b_k \quad (17)$$

Where a_k and b_k are linear coefficients, determined by the input image and the estimated rough transmission and N is the number of pixels in the window w_k.

Image Restoration: Finally, Image is recuperated using the equation (14) of DCP method. In IDCP using guided filter method value of low bound transmission map ranges from 0.1 -0.75 which is necessary to keep some amount of fog in the image.

Advantages:
- This method could eliminate halo effects effectively.
- It could refine transmission map to a great extent.
- It could get more accurate value of the global atmospheric light to avoid the haze-free image of looking dim.

Disadvantages:
- It can’t estimate the airlight accurately
- It can’t be able to improve contrast of an image.

2.4. Anisotropic Diffusion

Anisotropic diffusion method [14] was proposed by A.K. Tripathi and S. Mukhopadhay to improve the contrast of an image in HSI color plane without user intervention. In this method, they introduced an algorithm which uses anisotropic diffusion to refine the airlight map obtained from dark channel prior method. This algorithm uses histogram stretching for post processing. It is widely used in consumer electronics, tracking and navigation, and entertainment industries. Block diagram explaining Anisotropic Diffusion is shown in Figure 6 as:

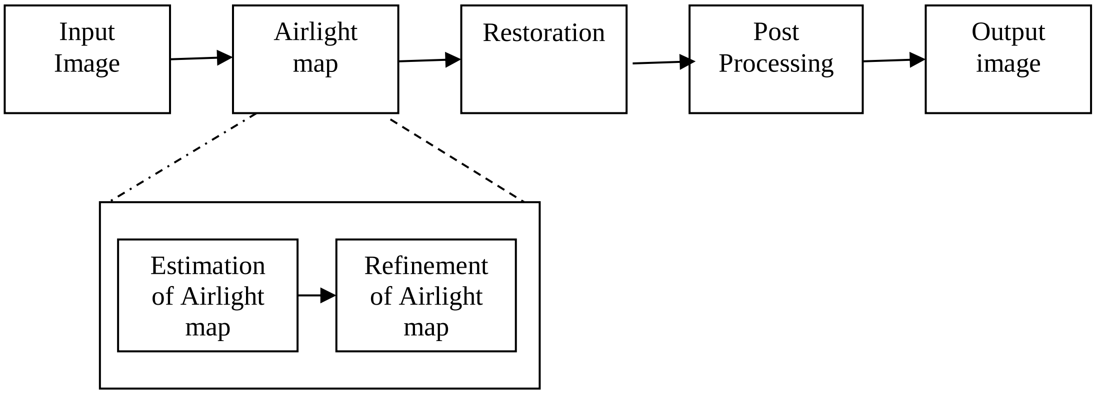


Figure 6. Block Diagram of Anisotropic Diffusion

Airlight Estimation: It is known that airlight is a positive quantity and estimated by equation (18) as given below:

$$A_{0(x,y)} = \beta \min_{c\varepsilon(r,g,b)} (I^c(x,y)) \quad (18)$$

Where, β is a constant whose value is in between 0 and 1 *i.e.* $0 < \beta < 1$.

Airlight Map Refinement: Airlight can be estimated iteratively from equation (19) as follows:

$$A^{t+1} = A^t + \lambda[\alpha \nabla A^t] \quad (19)$$

Where, λ is smoothing parameter whose value is between 0 and 1 *i.e.* $0 < \lambda < 1$. As stated by Perona-Malik, discrete version of equation (19) is given as:

$$A(x,y,t+1) = A(x,y,t) + \lambda[\alpha_N(x,y,t)\nabla_N A(x,y,t) + \alpha_S(x,y,t)\nabla_S A(x,y,t)] + \alpha_E(x,y,t)\nabla_E A(x,y,t) + \alpha_W(x,y,t)\nabla_W A(x,y,t) \quad (20)$$

Where, N, S, E and W represents North, South, East and West respectively. Symbol ∇ indicates nearest-neighbor differences.

Image restoration: Image is recuperated as given by equation (21):

$$I_0(x,y,c) = \frac{(I(x,y,c) - A(x,y))}{(1 - (A(s,y)/I_\infty(c)))} \quad (21)$$

Where, c ε R, G and B color plane.

Post Processing: Anisotropic Diffusion improves the contrast of an image using histogram equalization or histogram stretching.

Advantages:
- It estimates the airlight accurately.
- It improves the contrast of an image.

Disadvantages:
- It can't be able to estimate the transmission map.
- Overall visibility of image is not improved.

3. Proposed Hybrid Approach

This section proposes the hybrid approach to improve the contrast as well as visibility of the image. For this purpose, we estimate the airlight using Anisotropic Diffusion [10] and transmission map using IDCP (Guided Filter) [5]. The block diagram of the complete process is shown in Figure 7 as:

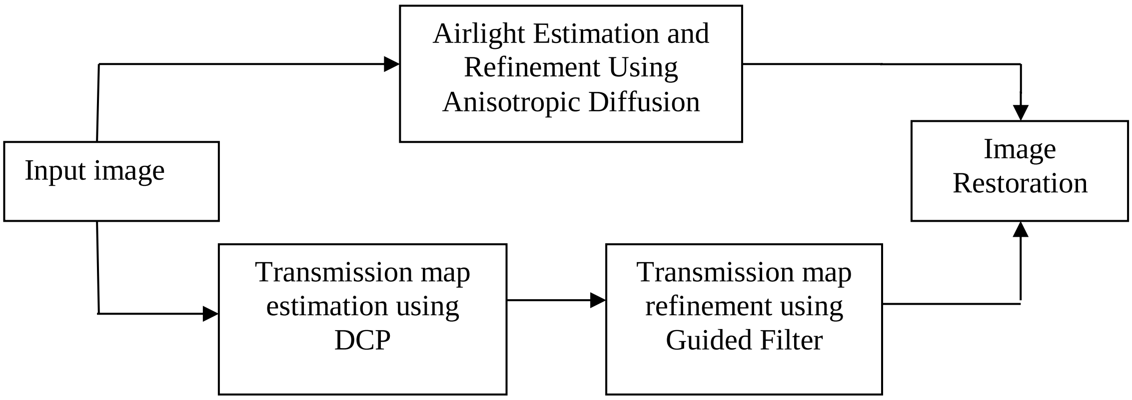


Figure 7. Block Diagram of Proposed Hybrid Approach

Let us now discuss each block in detail:

3.1 Airlight Estimation: It is known that airlight is a positive quantity and estimated by equation (22) as given below:

$$A_{0(x,y)} = \beta \min_{c\varepsilon(r,g,b)} (I^c(x,y)) \quad (22)$$

Where, β is a constant whose value is in between 0 and 1 *i.e.* $0 < \beta < 1$.

3.2 Airlight Map Refinement: Airlight can be estimated iteratively from equation (23) as follows:

$$A^{t+1} = A^t + \lambda[\alpha\nabla A^t] \quad (23)$$

Where, λ is smoothing parameter whose value is between 0 and 1 *i.e.* 0< λ <1. As stated by Perona-Malik, discrete version of equation (23) is given as:

$$A(x,y,t+1) = A(x,y,t) + \lambda[\alpha_N(x,y,t)\nabla_N A(x,y,t) + \alpha_S(x,y,t)\nabla_S A(x,y,t)] + \alpha_E(x,y,t)\nabla_E A(x,y,t) + \alpha_W(x,y,t)\nabla_W A(x,y,t) \quad (24)$$

Where, N, S, E and W represents North, South, East and West respectively. Symbol ∇ indicates nearest-neighbor differences.

3.3 Transmission Map Estimation: Transmission map is estimated using equation given below

$$\check{t}(x) = 1 - w * min_{y\in p(x)}\left(min_c\left(\frac{I^c(x)}{A^c}\right)\right) \quad (25)$$

Where, w is a constant whose value lies between 0 and 1; p(x) represents the patch of 15×15.

3.4 Transmission Map Refinement: Guided filter [13] operation is defined by equation (26) as given below:

$$t(i) = 1/\mathrm{N} \sum_{\mathrm{k:i\epsilon w_k}} \mathrm{a_k I_i} + \mathrm{b_k} \quad (26)$$

Where a_k and b_k are linear coefficients, determined by the input image and the estimated rough transmission and N is the number of pixels in the window w_k.

3.5 Image Restoration: Finally, Image is recuperated using the equation (27) as given below:

$$J(x) = \frac{(I(x)-A)}{(max(t(x),t_o))} + A \quad (27)$$

The value of low bound transmission map ranges from 0.1 -0.75 which is necessary to keep some amount of fog in the image and SNR.

4. Simulation Setup Parameters

For experimental analyses, we used the real foggy images. The simulation setup parameters required for above techniques are given in Table 1 and 2. Table 1 is common for all the techniques while simulation set up parameters used for various methods discussed above are given in Table 2.

Table 1. Simulation Setup Parameters

Tools	Specification
Software Used	MATLAB 2009
System Ram	4 G.B.
System Processor	Intel(R)Core(TM) i3
CPU	4005U @ 1.70ghz

Table 2. Defogging Algorithm Parameters

DCP Technique		
Symbol	Parameter	Value
ꞷ	Constant	0.95
t_0	Minimum Transmission Limit	0.1
P(x)	Patch Size	15×15
IDCP Technique		
t_0	Minimum Transmission Limit	0.35
p(x)	Patch Size	31×31
IDCP using Guided Filter Technique		
A	Constant	2
ꞷ	Constant	0.95
t_0	Minimum Transmission Limit	0.75
p(x)	Patch Size	15×15
Anisotropic Diffusion Technique		
p(x)	Patch size	15×15
B	Constant	0.9
K	Kappa	20

Λ	Smoothing parameter	1/7
A	Conduction Coefficient	0/1
Proposed Hybrid Approach		
p(x)	Patch size	15×15
B	Constant	0.9
K	Kappa	20
Λ	Smoothing parameter	1/7
A	Conduction Coefficient	0/1
Ꮻ	Constant	0.95
t_0	Minimum Transmission Limit	0.75

Performance Metrics:

Various Performance metrics used in simulation are described below:

- **Normalized Color Difference (NCD):**
  It issued to measure the degradation in color quality in color images.

- **Computation Time:** It is the time taken by algorithm to remove fog. Lower the value of computation time, Faster is the algorithm.

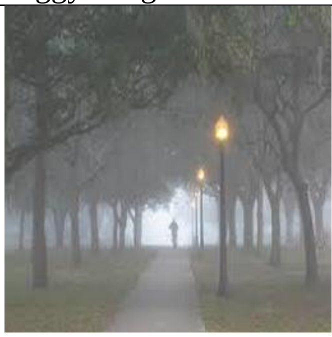
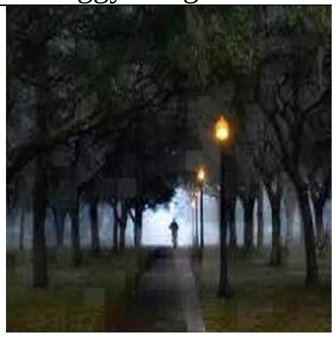
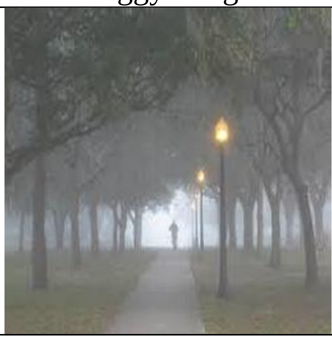
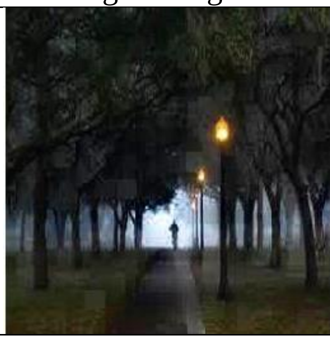
- **Contrast Gain:** It is defined as mean contrast difference between the foggy image and defogged image. Higher the value of contrast gain [16] better is the result obtained.

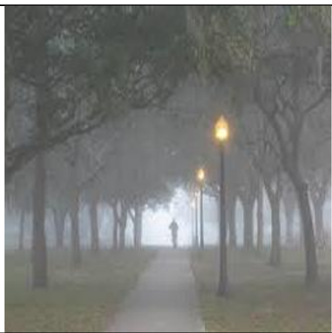
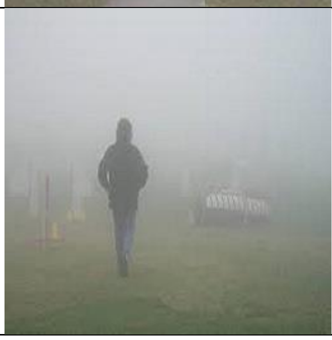
- **Percentage of Number of Saturated pixels:** It defined as percentage of number of pixel of recovered image which gets saturated. Lower the value of number of saturated pixel [17] better is the result obtained.

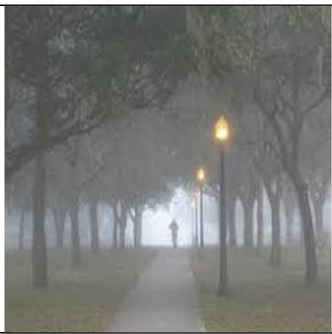
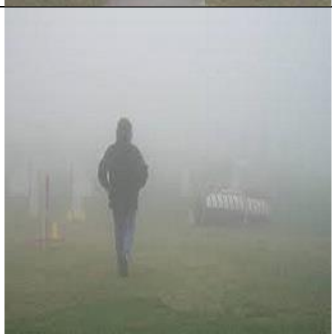
- **Color Naturalness Index:** It is used to measure the degree of association between human perception and reality world. The maximum value of CNI [18-19] is 1 while minimum is 0.

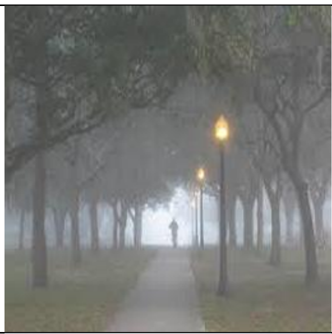
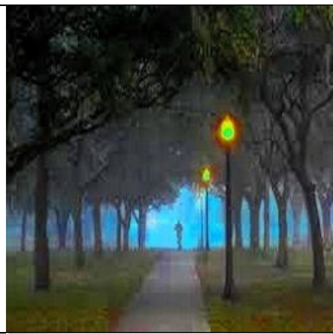
5. Experimental Results

Figure 8 represents the snapshots of various defogging techniques discussed above. Results of our hybrid proposed method shows best visible quality compared to previously discussed techniques used to defog the images.

Method	Foggy Image	De-foggy Image
DCP		
		
		
		
	Figure 8(a) Original Foggy Images	Figure 8(b) Recovered Images using DCP
IDCP		

		
		
		
	Foggy Images	Figure 8(c) Recovered Images using IDCP
IDCP using Guided Filter		
		

		
		
	Foggy Images	Figure 8(d) Recovered Images using IDCP (Guided Filter)
Anisotropic Diffusion		
		
		

		
	Foggy Images	Figure 8(e) Recovered Images using Anisotropic Diffusion
Proposed Technique		
		
		
		
	Foggy Images	Figure 8(f) Recovered

		Images using Proposed Algorithm

Figure 8. Snapshots of Various Defogging Techniques

5.1. Impact on Color Naturalness Index (CNI)

Figure 9 shows the impact of various defogging techniques on CNI. The following inference can be drawn from the figure:

- Ascending Order of CNI for various techniques:

IDCP (Guided Filter) < Anisotropic Diffusion < IDCP < DCP < Proposed Technique

- Closer the value of CNI to 1, more natural is the image.
- CNI of proposed technique is highest among all the techniques discussed.

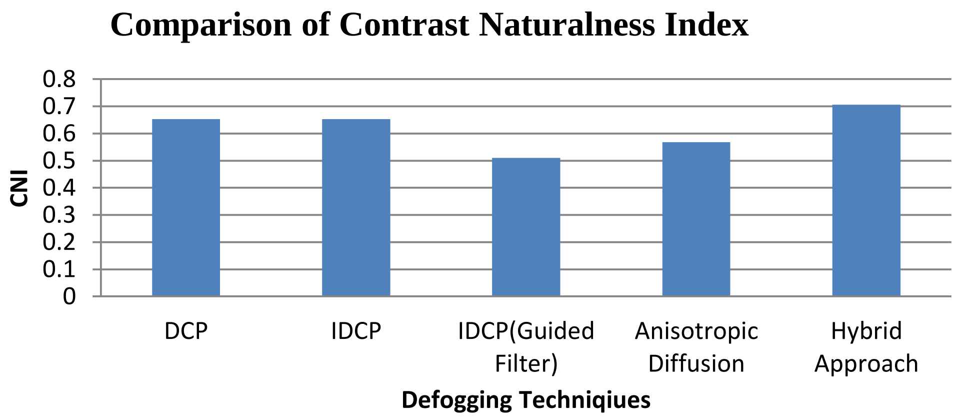


Figure 9. Color Naturalness Index (CNI) Vs Defogging techniques

5.2. Impact on Normalized Color Difference (NCD)

Figure 10 shows the impact on Normalized Color Difference (NCD) of various defogging techniques discussed above. The following interference can be drawn from the figure as:

- Descending order of value of NCD for various defogging techniques is given as:

Anisotropic Diffusion > DCP > IDCP > IDCP (Guided Filter) > Proposed Technique

- Smaller the value of NCD better is the result.
- NCD of proposed technique is least among all the defogging techniques.

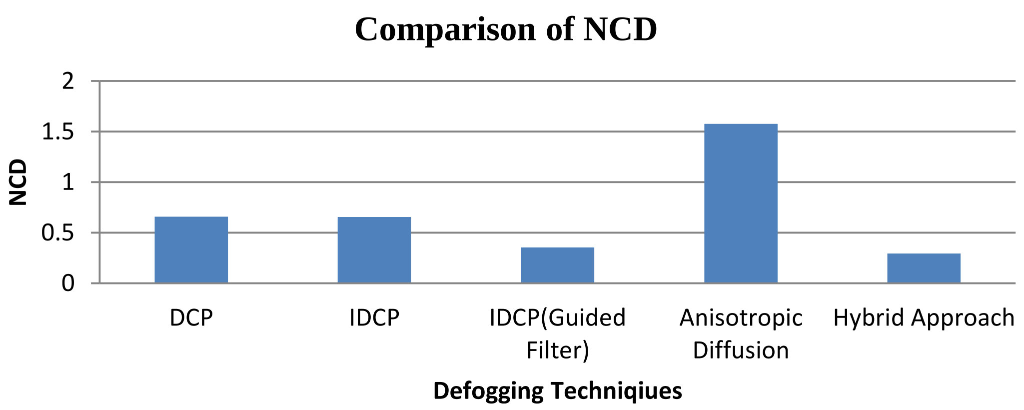


Figure 10. Normalized Color Difference Vs Defogging Techniques

5.3. Impact on Percentage of No of Saturated Pixels

Table 3 shows the value of Percentage of number of saturated pixel for various defogging techniques discussed above. Its value is least i.e. 0 for both IDCP (Guided Filter) as well as Proposed Technique.

Table 3. Percentage of No of Saturated Pixel

Method	DCP	IDCP	IDCP(Guided Filter)	Anisotropic Diffusion	Proposed Technique
Percentage of no of saturated pixel	4.07E-05	2.54E-05	0	0.0152	0

6. Conclusion

Table 4 shows the overall comparison of our proposed hybrid approach with the DCP and its variants. The following inference can be drawn:

- Halo effects have been removed significantly.
- Edges get preserved by the proposed method.
- CNI of proposed method is better among all.
- NCD of proposed method shows best result among all others.
- Visual quality of image is improved.
- In terms of time complexity, our result lies in between anisotropic diffusion and DCP.

Table 4. Comparison of Various Defogging Algorithms in Terms of Performance Metrics

Parameter	DCP	Improved DCP	Anisotropic Diffusion	IDCP(Guided Filter)	Proposed
TIME	VERY HIGH	HIGH	VERY LOW	LOW	LOW
HALO EFFECT	VERY HIGH	MEDIUM	LOW	LOW	VERY LOW
EDGE PRESERVATION	VERY LOW	LOW	LOW	MEDIUM	VERY HIGH
COLOR NATURALNESS INDEX	HIGH	HIGH	LOW	VERY LOW	VERY HIGH
NORMALIZED COLOR DIFFERNCE	HIGH	HIGH	VERY HIGH	LOW	VERY LOW

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