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# An in-Depth Analyses of Various Defogging Techniques

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### *Abstract*

*In the recent years, dehazing images have been extensively studied by researchers in various applications like in traffic monitoring, video surveillance, video security, marine surveillance etc. Various methods that make use of single image have been proposed such as: Dark Channel Prior (DCP), Improved Dark Channel Prior (IDCP), IDCP with Guided filter, Anisotropic Diffusion and DCP with Histogram specification. This paper is an effort to compare the above mentioned techniques on the basis of picture quality and parameters like Contrast gain (Cgain), Color Naturalness Index (CNI), Number of saturated pixel (σ), Normalized Color Difference (NCD) and Time Complexity (TC). It is observed that the best perceptual quality is obtained for IDCP with Guided Filter followed by IDCP, DCP with Histogram Specification, Anisotropic Diffusion and DCP.*

***Keywords:*** *Dehaze image, Transmission map, Air-light*

## 1. Introduction

Fog [1-2, 20-21], a combination of direct attenuation [1, 6] and air-light [1, 6] not only degrades the image quality [3] but also reduces the overall contrast of the scene (see Figure 1). Therefore, to remove it from the picture captured in hazy weather is a difficult task for researchers. In order to obtain a perfect image i.e. fog free image, distance of object in the scene should be known (see equation (1)) [1-2, 5-6]

**Figure 1. Real Foggy Image**

$$Image = J(x)\, e^{-\beta d(x)} + A * \left(1 - e^{-\beta d(x)}\right) \quad (1)$$

Where,

*J(x) represents scene radiance*

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*β represents scattering coefficient*
*d(x) is the scene depth*
*A represents the global atmospheric light.*

For this purpose, various methods were developed to estimate distance and that too using multiple images but these methods were having several disadvantages such as they cannot be applied to dynamic scenes, high tendency to errors because of moving objects and also time complexity of the process is high due to use of multiple images. Hence researchers focused their attention on the usage of single image. Various methods [7-14, 21-22] that use single image have been proposed such as Dark Channel Prior (DCP) [7-8], Improved Dark Channel Prior (IDCP) [11], IDCP using Guided Filter [12-13], Anisotropic Diffusion [15] and DCP with histogram specification [14]. These methods have several advantages with certain limitations too. In this paper, we try to identify the shortcomings of these techniques and compare them in term of few performance metrics.
The rest of paper is organized as follow: Section 2 contains the literature survey of the technique that uses single image, Section 3 contains experimental set up parameters and performance metrics used in this paper and section 4 contains the results of defogging techniques followed by conclusion and references.

## 2. Literature Survey

This section explains the various techniques used for de-fogging images.

1) **Dark Channel Prior:** Dark Channel Prior was first proposed by He, K., Sun, J., Tang, X in the year 2009. It uses a single image to remove fog by estimating both air-light as well as transmission map. The steps for DCP are as follows:

**Step 1-** Input a foggy image I(x, y).
**Step 2-** Compute the Dark Channel using equation (2) given below:

$$J_{dark}(x) = min_{c\in}\{r,g,b\}\left(min_{y\in p(x)}\left(I_c(y)\right)\right) \quad (2)$$

Where Ic is a color channel of J and p(x) is a local patch centered at x. Here, we take patch (window) size of 15×15.
**Step 3-** Estimate the air-light [1] by choosing the top 0.1% brightest pixel of dark channel and consider the pixel with highest intensity as air-light.
**Step 4-** Estimate transmission map [6] using equations given below:

$$\tilde{t}(x) = 1 - min_{y\in p(x)}\left(min_c\left(\frac{I^c(x)}{A^c}\right)\right) \quad (3)$$

Where $I^c(x)$ is the intensity of $x^{th}$ pixel of foggy image I; t(x) is transmission map; and A is global atmospheric light.

Modified transmission map so that image looks more natural is given by equation (4):

$$\tilde{t}(x) = 1 - w * min_{y\in p(x)}\left(min_c\left(\frac{I^c(x)}{A^c}\right)\right) \quad (4)$$

**Step 5-** Now, refine transmission map using soft matting [9] technique or bilateral filter [10]. Soft matting is explained below:
(i) First, minimize the cost function E(y) by rewriting t(x) and $\tilde{t}(x)$ as t and $\tilde{t}$ respectively.

$$E(y) = t^T Lt + \lambda(t - \tilde{t})^T(t - \tilde{t}) \quad (5)$$

Here, 1st term represents the smoothness term and 2nd term represents the data term having weight λ. L is laplacian [6] matrix whose elements are given by equation (6):

$$\sum_{k|(i,j)\in w_k}\left(\delta_{ij}-\frac{1}{|w_k|}\left(1+(I_i-\mu_k)^T\left(\Sigma_k+\frac{\varepsilon}{|w_k|}U_3\right)^{-1}(I_j-\mu_k)\right)\right) \qquad (6)$$

Where, Ii and Ij are the colors of the input image I at pixels i and j, δij is the Kronecker delta, μk and $\Sigma_k$ 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 $w_k$.

(ii) Refined transmission map can be obtained by solving sparse linear system given below:

$$(L+\lambda U)t=\lambda\tilde{t} \qquad (7)$$

**Step 6-** Finally, the image is restored by using equation (8):

$$J(x)=\frac{(I(x)-A)}{(max(t(x),t_o))}+A \qquad (8)$$

Where $t_o$=0.1.

This method uses single image for fog removal hence can be applied for dynamic scenes. It accurately estimates the transmission map using dark channel prior. At the same time, it offers several disadvantages such as: Assumption has been made for estimation of air-light, can't be suitable for pictures which have objects that resemble the white region i.e. snowy ground, produces halo effects and has very time complexity due to use of soft matting technique.

2) **Improved Dark Channel Prior (IDCP):** IDCP was proposed by Yan Wang, Bo Wu in the year 2010. It uses the same concept as used by DCP but at same time provides improvement for estimation of air-light by increasing the patch size to 31 × 31. It also resolves the problem of sky region faced in DCP. Also, time complexity of algorithm reduces since it avoids making use of soft matting technique. The steps of IDCP algorithm are as given below:

**Step 1-** Repeat steps 1-2 of DCP method.

**Step 2-** Air-light is estimated using the following algorithm:

(i) Find a region which appears to be farthest from the camera and used a rectangle to select it.

(ii) Create the dark channel in the selected rectangular region to properly estimate the transmission map.

**Step 3-** Estimate the transmission map by following step 4 of DCP method as mentioned above.

**Step 4-** Finally, recuperate the image using equation (8) given above in DCP. In IDCP, it uses $t_0$=0.35 instead of 0.1.

IDCP no doubt resolves the problem of DCP to a great extent but at same time not able to remove the halo effect problem faced by DCP and also doesn't provide any refinement for transmission map.

### 3) Improved Dark Channel Prior using Guided Filter

IDCP using guided filter was proposed by Yingi Xiong, Hua Yan, Chao Yu in the year 2013, to remove halo effects. It provides good estimation of air-light using imaging law of densest region which avoids the haze free image looks dim. It also provides an alternate mechanism for estimation of transmission map which is further refined using guided filter. The algorithm of IDCP using Guided Filter is as follows:

**Step 1-** Input a foggy image I(x, y).
**Step 2-** Compute the Dark Channel (see equation (2)) given above in DCP method.
**Step 3-** For estimation of air-light, choose the densest region and then follow the algorithm given below:
(i) Pixels of densest region should satisfy the two condition:

- $f(x,y) = max_{c\in(R,G,B)} I^c(x,y) - min_{c\in(R,G,B)} I^c(x,y) < \alpha$ (9)

Where f is foggy image deviation map, α is a constant ranging from 1-5.

- Pixel is top 0.5% brightest pixel of dark channel calculated by step 2.

(ii) Select A as the max R, G, B value among the densest region pixels. If A is found to be 0 then increase the value of α and go to (i).

**Step 4-** IDCP using Guided Filter estimate the transmission map using a mechanism as expressed below:

$$t'(x,y) = \begin{cases} 1, f(x,y) < \sigma \,\&\, I^{dark}(x,y) > \mu \\ \tilde{t}(x,y) \end{cases} \quad (10)$$

Where, $\tilde{t}$(x, y) is given by equation (4) explained in DCP method. The value of σ should range from 4-10 and μ is calculated by OTSU method.
**Step 5-** Transmission map is refined using Guided Filter [13] which is explained below:

$$t(i) = 1/N \sum_{k:i\epsilon w_k} a_k I_i + b_k \quad (11)$$

Here, $a_k$ and $b_k$ are linear coefficient calculated by input image and rough transmission map. N is the total number of pixel in window $w_k$.
**Step 6-** Finally, the image is restored by using same equation (8) as used for DCP method. But, in IDCP using guided filter, the lower bound for transmission i.e. $t_0$ varies from 0.1-0.75 and we took $t_o$=0.75.

IDCP using Guided Filter provides a good approach for fog removal but it is not able to improve the overall contrast of the restored image.

3) **Anisotropic Diffusion:** It was proposed by A. K. Tripathi and S. Mukhopadhyay in 2012, to improve the contrast of an image using HSI plane. It provides the best estimation of air-light independent of amount of fog present in input image, which further reduces computational time. The algorithm of anisotropic diffusion is as follows:

**Step 1-** Input the foggy image I(x, y).
**Step 2-** Air-light is a positive quantity and can be estimated using equation below:

$$A_o(x,y) = \beta^{min}_{c\in(r,g,b)}\left(I^c(x,y)\right) \quad (12)$$

Where, β lie between 0 and 1.
**Step 3-** For Refinement of air-light, it can be estimated as follows:

$$A^{t+1} = A^t + \lambda[\alpha \nabla A^t] \quad (13)$$

Where α is conduction coefficient, ∇ is gradient operator & λ is smoothing parameter whose values is in between 0-1.
The discrete version of equation (13) is given by Perona - Malik as follows:

$$A(x,y,t+1) = A(x,y,t) + \lambda[\alpha_N(x,y,t)\nabla_N A(x,y,t) + \alpha_S(x,y,t)\nabla_S A(x,y,t)] + \alpha_E(x,y,t)\nabla_E A(x,y,t) + \alpha_W(x,y,t)\nabla_W A(x,y,t) \quad (14)$$

Where, N, S, E and W are the mnemonic subscripts for North, South, East and West.

**Step 4-** The image is restored using equation (15) given below:

$$I_0(x,y,c) = \frac{(I(x,y,c) - A(x,y))}{(1-(A(s,y)/I_\infty(c)))} \quad (15)$$

**Step 5-** At last, contrast of recovered image is improved using histogram equalization or histogram stretching.

This method doesn’t able to estimate good value of transmission map and the overall visibility of image is not improved.

4) **DCP with Histogram Specification:** DCP with Histogram Specification was proposed by Shuai Yang, Qingsong Zhu, Jianjun Wang, Di Wu, and Yaoqin Xie in the year 2013. It overwhelms the defects of DCP techniques i.e. DCP will have tendency to reduce the contrast of haze free image. It lightens the background region by building histogram. For this purpose, it coverts R, G, B image into HSI plane using formula given below:

$$H = \begin{cases} \theta & B \le G \\ 360 - \theta & B > G \end{cases} \quad (16)$$

Where,

$$\theta = across \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}} \quad (17)$$

$$S = 1 - \frac{3}{R+G+B}[min(R,G,B)] \quad (18)$$

$$I = \frac{1}{3}(R,G,B) \quad (19)$$

This method provides separate algorithm for image having large background with low contrast and general foggy image as explained below:

**A) Algorithm for Large Background Region and Low Contrast:**

**Step 1-** Input the foggy image I(x, y).
**Step 2-** Build the histogram P for the input foggy image and find the intensity $x_p$ corresponding to the peak in high intensity region.
**Step 3-** Recover the image by repeating Step 2-6 of DCP technique explained above.
**Step 4-** Build the histogram Q of recovered fog free image, find the start point $x_Q$ of the sharp points in histogram Q.
**Step 5-** Divide the histogram Q into two parts by the point $x_Q$. Q1, the low intensity part represents the foreground distribution and Q2, the high intensity part represents the background distribution.
**Step 6-** Rebuild Q2 and then use a quadratic function to replace Q2 by setting $x_P$ and $x_Q$ as start point and end point respectively and the function value is adaptively determined by histogram Q.
**Step 7-** Combine the Q1 and rebuilt Q2 and apply histogram specification to rebuild Q

**Step 8-** Finally, we recuperate our contrast improved image.

**B) Algorithm for general foggy image:**

**Step 1-** Choose the fog free image by following step 1-5 of above algorithm A.
**Step 2-** Rebuild the histogram by selecting the right edge of Q1 and stretching it to region Q2.
**Step 3-** Apply histogram specification to rebuild Q.
**Step 4-** Finally, we recuperate our image.

This method fails to improve DCP results in case of high intensity of foreground and background region. At same time, it produces grey scale degeneracy on image during histogram specification.

## 3. Simulation Setup

To compare the performance of all the defogging techniques discussed above, a simulator is designed in MATLAB-10. The following performance metrics are used for analysis of performance of all techniques:

**1) Performance Analysis Metrics:**

1. **Normalized Color Difference (NCD):** It is used to measure the color difference between the de-foggy and foggy image. It is defined as the degradation of color quality in color image. Mathematically, NCD in L*u*v color plane can be expressed as:

$$NCD_{luv} = \frac{\sum_{i=1}^{Y}\sum_{j=1}^{X}\Delta E_{luv}}{\sum_{i=1}^{Y}\sum_{j=1}^{X} E_{luv}}$$

Where, X and Y presents image dimensions.

$$\Delta E_{luv} = [(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2]^{1/2} \quad \&$$

$$E_{luv} = [(L^*)^2 + (u^*)^2 + (v^*)^2]^{1/2}$$

2. **Contrast Gain ($C_{gain}$) [16]:** It is defined as mean contrast difference between de-foggy and foggy image. It can be expressed as:

$$C_{gain} = \bar{C}_{I_{defoggy}} - \bar{C}_{I_{foggy}}$$

Mean contrast is given as:

$$\bar{C}_I = \frac{1}{XY}\sum_{j=0}^{Y-1}\sum_{i=0}^{X-1} C(x,y)$$

Where,

$$C(x,y) = \frac{s(x,y)}{m(x,y)}$$

Where,

$$m(x,y) = \frac{1}{(2p+1)^2} \sum_{l=-p}^{p} \sum_{k=-p}^{p} E(x+l, y+k)$$

$$s(x,y) = \frac{1}{(2p+1)^2} \sum_{l=-p}^{p} \sum_{k=-p}^{p} |E(x+l, y+k) - m(x,y)|$$

3. **Number of saturated pixel (σ) [17]**: It can be expressed as:

$$\sigma = \frac{n}{X \times Y}$$

Where, n represents the total number of pixels which are saturated after fog removal.

4. **Color Naturalness Index (CNI) [18-19]:** It is used to measure the degree of association between the human perception and natural world in CIELUV color plane. It can be expressed as:

$$CNI = \frac{(n_{skin} \times N_{skin} + n_{grass} \times N_{grass} + n_{sky} \times N_{sky})}{(n_{skin} + n_{grass} + n_{sky})}$$

Where, $n_{skin}$ is the number of pixel hue value in between 25-70; $n_{grass}$ is in between 95-135 and $n_{sky}$ is in between 185-260.

$$N_{skin} = exp\left(-0.5 \times \left( {(S_{avg\_skin} - 0.76)}/{0.52} \right)^2\right)^4$$

$$N_{grass} = exp\left(-0.5 \times \left( {(S_{avg\_grass} - 0.81)}/{0.53} \right)^2\right)$$

$$N_{sky} = exp\left(-0.5 \times \left( {(S_{avg\_sky} - 0.43)}/{0.22} \right)^2\right)$$

Here, $S_{avg\_skin}$ is the average saturation value for skin pixels; $S_{avg\_grass}$ for grass pixels and $S_{avg\_sky}$ for sky pixels.

5. **Time Complexity (TC): It** is defined as the total time taken by algorithm to remove fog from an image. It is expressed in seconds.

6. **Perceptual Quality:** De-foggy image should have high perceptual quality so that image looks more real for the observer. It should not possess color blurriness.

### 2) Set up Parameters

In this paper, we used real foggy images. Parameters given in Table 1 are common to all defogging techniques. Table 2 gives set up parameters used for different techniques discussed above.

**Table 1. Simulation Setup Parameters**

| Parameter | Specification |
|---|---|
| | |

| | |
|---|---|
| Image | Woods<br>Rural Morning<br>Pond |
| Image Type | Png |
| Software | MATLAB-2010 |
| RAM | 4 GB |
| Processor | Intel(R)Core(TM) i3 |
| CPU | 4005U @ 1.70ghz |

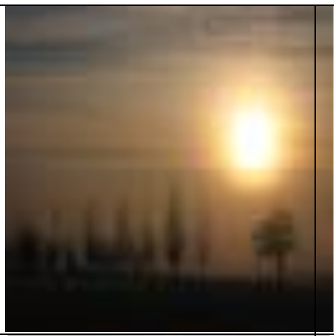
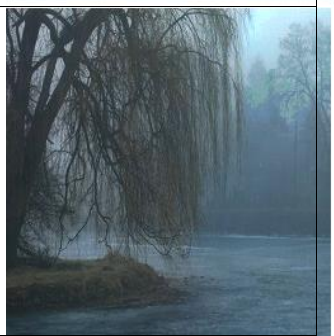
**Table 2. De-foggy Algorithms Parameters**

| Symbol | Parameter | Value |
|---|---|---|
| DCP | | |
| p(x) | Patch size | 15×15 |
| w | constant | 0.95 |
| $t_o$ | Lower transmission limit | 0.1 |
| IDCP | | |
| p(x) | Patch size | 31×31 |
| w | Constant | 0.95 |
| $t_o$ | Lower Transmission Limit | 0.35 |
| IDCP using Guided Filter | | |
| p(x) | Patch size | 31×31 |
| α | Constant | 2 |
| w | Constant | 0.95 |
| $t_o$ | Lower transmission limit | 0.75 |
| Anisotropic Diffusion | | |
| p(x) | Patch size | 15×15 |
| β | Constant | 0.9 |
| k | kappa | 20 |
| λ | Smoothing parameter | 1/7 |
| α | Conduction Coefficient | 0/1 |
| DCP with Histogram Specification | | |
| p(x) | Patch size | 15×15 |
| w | constant | 0.95 |
| $t_o$ | Lower transmission limit | 0.1 |

## 4. RESULTS

This section discussed the results of simulation based on performance metrics:

1. **Impact on Perceptual Quality:** Figure 2 shows the snapshots of output defogging image obtained from various defogging techniques. From the snapshots, it is observed that the best image quality was obtained from IDCP using guided filter since it completely removes halo effects, blurriness and odd region.

| | | | |
|---|---|---|---|
| Original foggy Image |  |  |  |
| DCP |  |  |  |
| IDCP |  |  |  |
| IDCP with Histogram specification |  |  |  |
| Anisotropic Diffusion |  |  |  |

| | | | |
|---|---|---|---|
| IDCP using Guided Filter |  |  |  |

**Figure 2. Snapshots of Various Defogging Techniques**

## 2. Impact of Various Defogging Techniques on TC, NCD, $C_{gain}$, σ, CNI:

The results of various defogging algorithm for different foggy images with image size 64×64, 128×128, 256×256, 512×512 are shown in Table 3-5 given below:

**Table 3. Impact of TC, NCD, $C_{gain}$, σ, CNI on Wood Image**

| Wood.png | Parameters | 64×64 | 128×128 | 256×256 | 512×512 |
|---|---|---|---|---|---|
| DCP | TC | 1.524912 | 3.035971 | 8.260957 | 33.701064 |
| | NCD | 0.1357 | 0.2709 | 0.3789 | 0.4712 |
| | Cgain | 0.0376 | 0.0556 | 0.0696 | 0.0733 |
| | σ | 0 | $5.0863\times10^{-6}$ | $1.017\times10^{-5}$ | $4.069\times10^{-5}$ |
| | CNI | 0.5350 | 0.5753 | 0.6528 | 0.7174 |
| IDCP | TC | 1.159501 | 2.011849 | 5.404304 | 21.759435 |
| | NCD | 0.1079 | 0.1733 | 0.2547 | 0.2945 |
| | Cgain | 0.0255 | 0.0453 | 0.0590 | 0.0614 |
| | σ | 0 | $0.0863\times10^{-6}$ | $1.0103\times10^{-5}$ | $2.069\times10^{-5}$ |
| | CNI | 0.5112 | 0.5347 | 0.5758 | 0.5873 |
| IDCP WITH HISTROGRAM SPECIFICATION | TC | 1.772841 | 3.903256 | 8.291213 | 34.094078 |
| | NCD | 0.0882 | 0.1104 | 0.1586 | 0.1839 |
| | Cgain | 0.0250 | 0.0266 | 0.0284 | 0.0259 |
| | σ | 0 | $1.0173\times10^{-5}$ | $2.8973\times10^{-5}$ | $3.0690\times10^{-5}$ |
| | CNI | 0.5029 | 0.5040 | 0.5238 | 0.5258 |
| IDCP (GUIDED | TC | 1.465423 | 2.945942 | 8.009210 | 25.637924 |

| | | | | | |
|---|---|---|---|---|---|
| FILTER) | NCD | 0.1002 | 0.1624 | 0.2338 | 0.2838 |
| | Cgain | 0.0249 | 0.0346 | 0.0479 | 0.0511 |
| | σ | 0 | 0 | 0 | 0 |
| | CNI | 0.5209 | 0.5536 | 0.5936 | 0.5601 |
| ANISTROPIC DIFFUSION | TC | 1.424351 | 2.775264 | 6.746964 | 22.811441 |
| | NCD | 0.7102 | 0.5556 | 0.5379 | 0.5222 |
| | Cgain | 0.2481 | 0.2099 | 0.1871 | 0.1456 |
| | σ | 0.0081 | 0.0236 | 0.0738 | 0.2548 |
| | CNI | 0.9113 | 0.8776 | 0.8665 | 0.8524 |

**Table 4. Impact of TC, NCD, $C_{gain}$, σ, CNI on Rural Morning Image**

| Rural Morning.png | Parameters | 64×64 | 128×128 | 256×256 | 512×512 |
|---|---|---|---|---|---|
| DCP | TC | 2.015361 | 3.125869 | 7.488125 | 31.145349 |
| | NCD | 0.1482 | 0.2905 | 0.4365 | 0.4590 |
| | Cgain | 0.0187 | 0.0411 | 0.030 | 0.0991 |
| | Σ | 0 | 0 | 0.0299 | 0.1048 |
| | CNI | 0.6715 | 0.7832 | 0.9280 | 0.9646 |
| IDCP | TC | 0.933295 | 1.566986 | 4.289498 | 17.335380 |
| | NCD | 0.1292 | 0.1564 | 0.2609 | 0.4566 |
| | Cgain | 0.0110 | 0.0172 | 0.0288 | 0.0978 |
| | Σ | 0 | 0 | 0 | 0.1018 |
| | CNI | 0.6371 | 0.6819 | 0.8410 | 0.9637 |
| IDCP WITH HISTROGRAM SPECIFICATION) | TC | 2.760812 | 4.083906 | 8.128632 | 33.478442 |
| | NCD | 0.0618 | 0.1450 | 0.1856 | 0.2986 |
| | Cgain | 0.0086 | 0.0139 | 0.0178 | 0.0156 |
| | σ | 0 | 0 | 0.0189 | 0.0790 |
| | CNI | 0.6168 | 0.6787 | 0.7814 | 0.8330 |

| | | | | | |
|---|---|---|---|---|---|
| IDCP (GUIDED FILTER) | TC | 1.522151 | 2.990486 | 6.823561 | 26.717637 |
| | NCD | 0.1179 | 0.1464 | 0.2601 | 0.4269 |
| | Cgain | 0.0102 | 0.0151 | 0.0254 | 0.0949 |
| | σ | 0 | 0 | 0 | 0 |
| | CNI | 0.6321 | 0.6910 | 0.8714 | 0.9621 |
| ANISTROPIC DIFFUSION | TC | 1.334374 | 2.235165 | 6.560118 | 27.856420 |
| | NCD | 0.5197 | 0.5071 | 0.5025 | 0.5030 |
| | Cgain | 0.1863 | 0.1450 | 0.1623 | 0.2070 |
| | σ | 0.0072 | 0.0175 | 0.0726 | 0.3638 |
| | CNI | 0.9501 | 0.9771 | 0.9720 | 0.9763 |

**Table 5. Impact of TC, NCD, $C_{gain}$, σ, CNI on Pond Image**

| Pond.png | Parameters | 64×64 | 128×128 | 256×256 | 512×512 |
|---|---|---|---|---|---|
| DCP | TC | 1.725739 | 2.920039 | 7.932986 | 32.559592 |
| | NCD | 0.3273 | 0.4945 | 0.6073 | 0.6169 |
| | Cgain | 0.0807 | 0.07809 | 0.0412 | 0.0372 |
| | σ | 0 | $2.54\times10^{-5}$ | 0 | $8.6460\times10^{-5}$ |
| | CNI | 0.5327 | 0.6273 | 0.6878 | 0.6823 |
| IDCP | TC | 1.269545 | 1.886249 | 5.564997 | 17.018605 |
| | NCD | 0.2515 | 0.3188 | 0.5512 | 0.6015 |
| | Cgain | 0.0641 | 0.0724 | 0.0405 | 0.03663 |
| | σ | 0 | 0 | 0 | $0.00158\times10^{-6}$ |
| | CNI | 0.5017 | 0.5374 | 0.6662 | 0.6658 |
| DCP WITH HISTROGRAM SPECIFICATION) | TC | 2.096221 | 3.240521 | 8.207259 | 34.278087 |
| | NCD | 0.1512 | 0.2145 | 0.2308 | 0.2316 |
| | Cgain | 0.0369 | 0.0349 | 0.0342 | 0.0324 |
| | σ | 0 | 0 | $7.1208\times10^{-5}$ | 0 |

| | | | | | |
|---|---|---|---|---|---|
| | CNI | 0.4902 | 0.4752 | 0.4747 | 0.4752 |
| IDCP (GUIDED FILTER) | TC | 1.664684 | 2.719246 | 7.803744 | 21.887307 |
| | NCD | 0.2490 | 0.3178 | 0.4551 | 0.5779 |
| | Cgain | 0.0612 | 0.0675 | 0.039 | 0.0357 |
| | σ | 0 | 0 | 0 | 0 |
| | CNI | 0.5027 | 0.5384 | 0.5936 | 0.6652 |
| ANISTROPIC DIFFUSION | TC | 1.513976 | 2.661029 | 7.606484 | 20.876189 |
| | NCD | 0.6459 | 0.6544 | 0.6725 | 0.6858 |
| | Cgain | 0.2237 | 0.1995 | 0.1757 | 0.1678 |
| | σ | 0.0082 | 0.0231 | 0.0654 | 0.2342 |
| | CNI | 0.9817 | 0.9806 | 0.9757 | 0.9753 |

- **Impact on Time Complexity:** Figure 3 shows the graph of time complexity versus various defogging algorithm for different image size for Wood.png image. It is observed from the graph that time complexity is best for IDCP algorithm because it doesn't use soft matting technique for transmission map refinement while TC is least for DCP with histogram specification algorithm since it makes use of soft matting technique as well as histogram specification for background contrast improvement. Therefore, removal of fog in terms of TC follows the order:

IDCP < Anisotropic Diffusion < IDCP using Guided Filter < DCP < DCP with Histogram Specification

From Figure 3, it is also quite clear that time complexity increases with increase in image size.

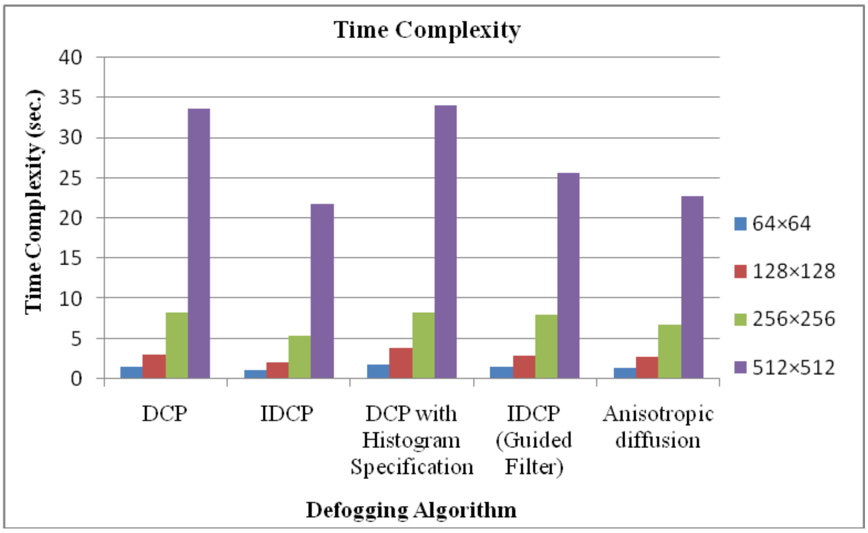



**Figure 3. Graph of Time Complexity**

- **Impact on Normalized Color Difference (NCD):** Figure 4 shows the graph of NCD versus various defogging algorithms with different image size for Wood.png image. It is observed from the graph that NCD has best result for DCP with Histogram specification algorithm because it has minimum NCD value than any other algorithm discussed here whereas it is slightly higher for IDCP using Guided Filter. Further, Anisotropic Diffusion has poor NCD result with maximum value. Hence, for removal of fog in terms of NCD follows the order:

Anisotropic Diffusion > IDCP > DCP > IDCP using Guided Filter > DCP with Histogram Specification

Lower the value of NCD better is the result. From graph, it is clear that as the image size increases, NCD value also increases for all the techniques except for Anisotropic Diffusion.

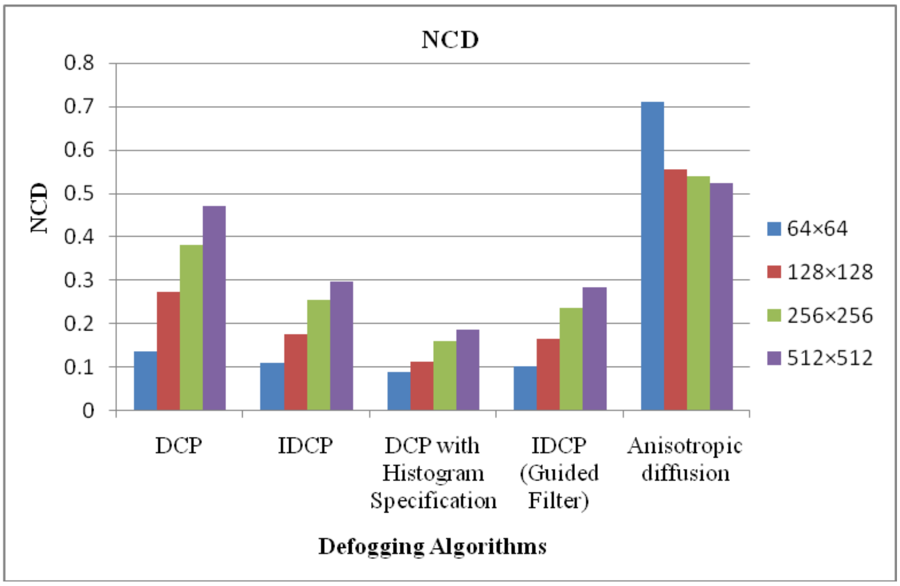



**Figure 4. Graph of Normalized Color Difference**

- **Impact on Contrast Gain (Cgain):** It is observed from the graph (see Figure 4) that Cgain has best result for Anisotropic Diffusion algorithm with maximum value because it uses histogram stretching for contrast improvement followed by DCP whereas DCP with histogram Specification has poor Cgain result with lowest value among all techniques discussed. Therefore, removal of fog in terms of Cgain follows the order:

Anisotropic Diffusion > IDCP > DCP > IDCP using Guided Filter > DCP with Histogram Specification

Higher the value of Cgain good is the result. From graph, it is clear that as the image size increases, Cgain value also increases for DCP, IDCP, IDCP (Guided Filter) while for Anisotropic Diffusion its value decreases with increase in image size. For DCP with Histogram Specification, Cgain remains constant regardless for image size.

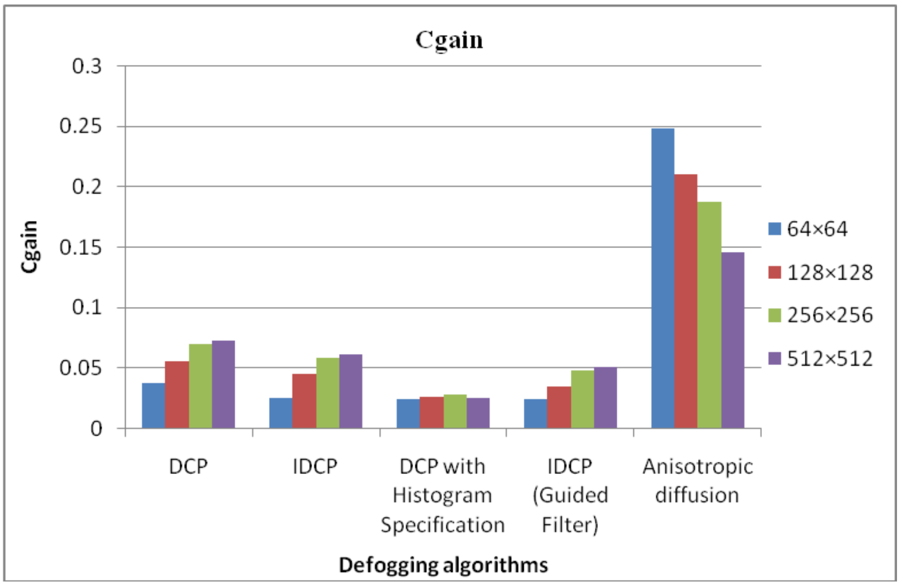



**Figure 5. Graph of Contrast Gain**

- **Impact on Number of Saturated Pixels (σ):** Figure 6 shows the graph of σ i.e. no. of saturated pixels versus various defogging algorithms with different image size for Wood.png image. It is observed that σ has best result for IDCP (Guided Filter) with 0 value i.e. Not even a single pixel is saturated after fog removal which is then followed by DCP. Anisotropic Diffusion has increase the Cgain to such an amount that it has maximum number of pixels which gets saturated and has poor σ result. Therefore, removal of fog in terms of σ follows the order:

Anisotropic Diffusion > DCP > DCP with Histogram Specification > IDCP > IDCP using Guided Filter

Lower the value of σ good is the result. From graph, it is clear that as the image size increases, σ value also increases for all defogging algorithm except for IDCP (Guided Filter) whose σ remains constant regardless for image size.

**Table 6. Number of Saturated Pixels**

| De-foggy Techniques | 64×64 | 128×128 | 256×256 | 512×512 |
|---|---|---|---|---|
| DCP | 0 | $5.0863\times10^{-6}$ | $1.017\times10^{-5}$ | $4.069\times10^{-5}$ |
| IDCP | 0 | $0.0863\times10^{-6}$ | $1.0103\times10^{-5}$ | $2.069\times10^{-5}$ |
| DCP WITH HISTROGRAM SPECIFICATION | 0 | $1.0173\times10^{-5}$ | $2.8973\times10^{-5}$ | $3.0690\times10^{-5}$ |
| IDCP (GUIDED FILTER) | 0 | 0 | 0 | 0 |
| ANISOTROPIC DIFFUSION | 0.0081 | 0.0236 | 0.0738 | 0.2548 |

**Impact on Color Naturalness Index (CNI):** Figure 6 shows the graph of CNI versus various defogging algorithms with different image size for Wood.png image. It is clear from graph that CNI has best result for Anisotropic Diffusion algorithm with maximum value followed by DCP whereas DCP with histogram Specification has poor CNI result with lowest value among all techniques discussed. Therefore, removal of fog in terms of CNI follows the order:

Anisotropic Diffusion > DCP > IDCP using Guided Filter > IDCP > DCP with Histogram Specification

Higher the value of CNI more natural is the image. From graph, it is clear that as the image size increases, CNI value also increases for all defogging algorithms discussed while for Anisotropic Diffusion its value decreases with increase in image size.

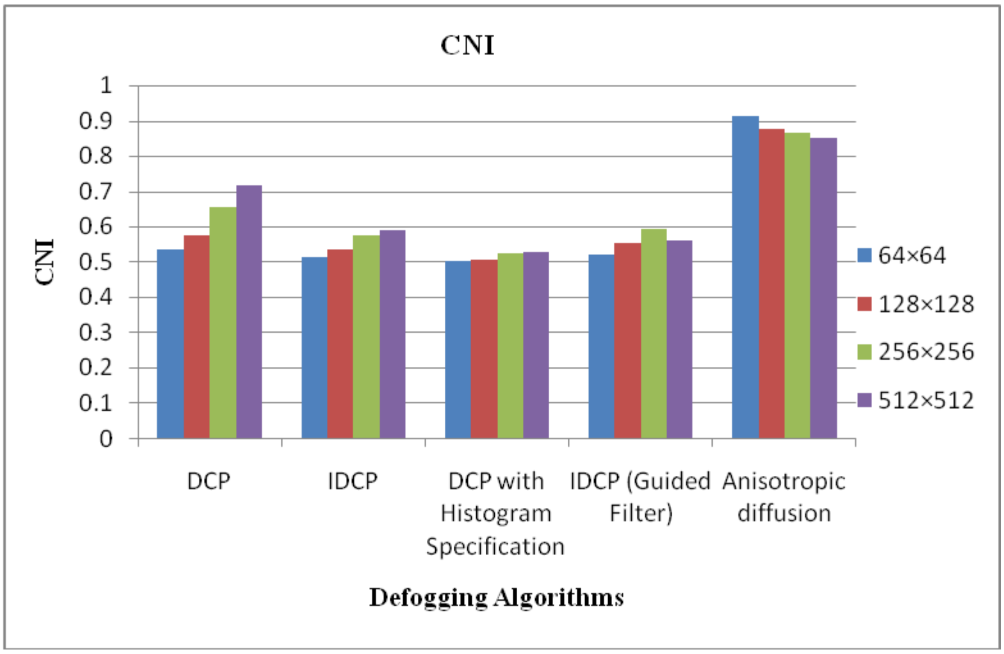



**Figure 6. Graph of Color Naturalness Index**

## 5. Conclusion

In this paper, various defogging techniques have been reviewed and compared in terms of performance metrics discussed above. From the analysis shown in Table 7, following conclusion has been drawn:

1. IDCP using Guided Filter gives the best result for fog removal among all the techniques.
2. Time complexity of IDCP is very low but has low perceptual quality while IDCP using Guided Filter gives good result with moderate time complexity.
3. Anisotropic Diffusion has highest value of CNI and Cgain which in turn improves the overall contrast of the image.
4. IDCP using Guided Filter in terms of perceptual image quality which is the most important parameter and number of saturated pixel among all the techniques since it provides best perceptual quality.
5. DCP with Histogram Specification provides best NCD result.

**Table 7. Comparison of Various Defogging Techniques**

| Performance Metric Parameters | DCP | IDCP | DCP with Histogram Specification | IDCP using Guided Filter | Anisotropic Diffusion |
|---|---|---|---|---|---|
| Perceptual Quality | * | **** | *** | ***** | ** |
| TC | ** | ***** | * | *** | ** |
| NCD | *** | * | ***** | **** | * |
| Cgain | **** | *** | * | ** | ***** |
| σ | ** | *** | **** | ***** | * |
| CNI | **** | ** | * | *** | ***** |

Where,
***** - BEST
**** - BETTER
*** - GOOD
** - POOR
* - WORST

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