Performance Comparison of Various Filters for Denoising Foggy Images

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ABSTRACT
This paper compares the performance of various filters on the images degraded by the fog. Denoising is vital for the image enhancement. It is difficult to remove the noise from the images while preserving the information and the quality of the image. For analysis filters like Median, Alpha Trim, Lee, Wiener, Anisotropic Diffusion and Guided filter are used. Number of performance metrics exists already in the literature to analyze the performance of denoising filters like SNR (Signal Noise Ratio), MSE (Mean Square Error), NAE (Normalized Absolute Error) and SC (Structural Content).The result demonstrates that the results of filters are not satisfactory. So, recently proposed dark channel prior method is studied and implemented. The visual results of the dark channel method are better than the filters.

Keywords
Denoising, Median Filter, Alpha trim filter, Lee filter, Wiener Filter, Anisotropic diffusion filter, Signal to Noise Ratio, Structural Content, Normalized Absolute Error, Mean Square Error, Dark Channel Prior Method.

1. INTRODUCTION
Image Denoising is the one of the fundamental challenges in the field of image processing and computer vision. The underlying goal is to estimate the original image by suppressing noise from a noise-contaminated version of the image. Image noise may be caused by different intrinsic (i.e., sensor) and extrinsic (i.e., environment) conditions like fog, mist, dust, haze etc. which are often not possible to avoid in practical situations. That's why image denoising plays an important role in many applications like image restoration, visual tracking, image segmentation and image classification. In the case of image degraded by the atmospheric condition, we don't have the original image of clear weather, it becomes difficult to restore the original image. But obtaining the original image content is crucial. In the literature, many algorithms have been proposed for image denoising but preserving the edge details is still difficult. In 2010, Wenshui Shen and Xinzhi Zhou used algorithm for removing thin cloud from remote sensing digital images based on homomorphic filtering [1]. In 201, Kristofor B. Gibson and Truong Q. Nguyen used the adaptive Wiener filter to remove fog from the image [2]. Raghvendra Yadav and Manoj Alwani enhanced the foggy images by using Histogram classification [4]. In 2013, Chanchal Srivastava et al. compared the performance of various filters and wavelet transform filters for image denoising [12]. In 2013, Govindaraj. V and Sengottaiyan.G survey on Image Denoising using Different Filters [5]. In 2013, Akanksha Jain and Prateek Nahar compare the two denoising method using adaptive wiener filter and fuzzy filter in wavelet domain [6].

2. FILTERS USED FOR DENOISING
This section presents a brief review on different filters like Median, Alpha Trim, Lee, Wiener, Anisotropic Diffusion and Guided filter

2.1 Median Filter
The median filter is a non-linear digital filtering technique [7]. It is often used to remove noise. It is best used for removing salt and pepper noise and impulse noise. In median filter, each entry is replaced with the median of the neighboring entries. The pattern of neighbors is called window, its center is moved entry by entry, replacing each entry with the median of neighboring pixels.

2.2 AlphaTrim Filter
Alpha-trim mean filter is a nonlinear digital filter [7]. It is also window based technique. It is the hybrid of mean and median filter. In this filter, first neighborhood coefficients including centered pixel under the window are sorted for each pixel. Then boundary pixels are removed and mean of remaining elements is calculated. It is mostly used for salt and pepper noise and Gaussian noise.

2.3 Wiener Filter
Wiener filters are a class of optimum linear filters [12]. The wiener filter provides a solution of signal estimation problem for stationary signals. It provides successful results in removing noise from photographic images. The design of the filter is distinct. It is based on statistical approach. The Wiener filter is used to minimize the mean square error between the estimated random process and the desired process.

2.4 Lee Filter
Lee Filter performs noise filtering on an image using first order local statistics from the neighborhood of a specified pixel. The Lee filter converts the multiplicative model into an additive by reducing the problem of dealing with speckle noise to a known tractable case. It is non-adaptive speckle filtering. In this filter the local mean and variance of the neighborhood is evaluated. In regions with no variance, the filter simply passes the mean value of the neighborhood. In the presence of variation, the original (input) pixel value is passed unchanged.

2.5 Anisotropic Diffusion Filter
Anisotropic Diffusion is a technique aiming at reducing image noise without removing significant parts of the image content, typically edges, lines or other details that are important for the interpretation of the image. This diffusion process is a linear and space-

invariant transformation of the original image. A more general formulation allows the locally adapted filter to be truly anisotropic close to linear structures such as edges or lines. Such methods are referred to as shape-adapted smoothing or coherence enhancing diffusion. Anisotropic diffusion can be used to remove noise from digital images without blurring edges. Along the same lines as noise removal, anisotropic diffusion can be used in edge detection algorithms. Anisotropic diffusion is implemented by calculating the means of the generalized diffusion equation. It reduces the diffusivity at the locations like edges. This likelihood is measured by $|\nabla u|^2$. This filter is based on the equation

$$\boldsymbol{\partial_t u = div(g(|\nabla u|^2)\nabla u)}$$

2.6 Guided Filter

The guided Filter was derived from the local linear model. The guided filters use the contents of a guide image as input image for filtering [18]. The guided filter is used as edge-preserving smoothing filter like the bilateral filter but has better behavior near the edges. It has a theoretical connection with the matting Laplacian matrix. It is more generic concept than a smoothing operator and can better utilize the structures from the guide image. It involves a guide image, I and an input image, p to filter yields an output image, q. Both I and p should be given beforehand according to the application, and these can be identical. The filtered output at a pixel, K is expressed as a weighted average:

$$\boldsymbol{q_i = \sum_j W_{ij}(I)p_j}$$

where i and j are pixel indexes. The filter kernel W_{ij} is a function of the guide image, I and is independent of p. The filter is linear with respect to p.

3. QUALITY MEASURES

Many quantative metrics have been defined in the literature to measure the performance of an algorithm. Some of the metrics have been explored here.

3.1 Signal to Noise Ratio

Signal to Noise Ratio (SNR) is used to quantify how much a signal has been corrupted by noise [8]. It is defined as the ratio of signal power to the noise power corrupting the signal. A ratio higher than 1:1 indicates signal is more than noise. SNR is expressed in the logarithmic decibel scale.

$$\mathrm{SNR} = 20 * log_{10}\left(\frac{\mathrm{Signal}}{\mathrm{Noise}}\right)$$

3.2 Mean Square Error

The most frequently used measures are deviations between the original and coded images in the image coding and computer vision literature [8]. The mean square error (MSE) and SNR are the most commonly used measures. The reason for their widespread popularity is their mathematical tractability and the fact that it is often straightforward to design system that minimizes the MSE but cannot capture the artifacts like blur or blocking artifacts. It is expressed as

$$\mathbf{MSE} = \frac{\mathbf{1}}{\mathbf{MN}}\sum_{\mathbf{i=1}}^{\mathbf{M}}\sum_{\mathbf{j=1}}^{\mathbf{N}}|\mathbf{X(i,j)} - \mathbf{\bar{X}(i,j)}|^{\mathbf{2}}$$

where M X N is size of original image; X (i,j) and $\bar{X}$(i,j) are the original image and the enhanced image respectively.

3.3 Normalized Absolute Error (NAE)

The larger value of NAE means that image is of poor quality [19]. NAE is defined as

$$\mathbf{NAE} = \sum_{\mathbf{i=1}}^{\mathbf{M}}\sum_{\mathbf{j=1}}^{\mathbf{N}}|\mathbf{X(i,j)} - \mathbf{\bar{X}(i,j)}| \bigg/ \sum_{\mathbf{i=1}}^{\mathbf{M}}\sum_{\mathbf{j=1}}^{\mathbf{N}}|\mathbf{X(i,j)}|$$

3.4 Structural Content (SC)

Correlation, a familiar concept in image processing, estimates the similarity of the structure of two signals. This measure compares total weight of an original signal to that of a coded or any noise added signal [19]. This measure is called as structural content. If it is spread at 1, then the decompressed image is of better quality and large value of SC means that the image is of poor quality. SC is defined as follows:

$$\mathbf{SC} = \sum_{\mathbf{i=1}}^{\mathbf{M}}\sum_{\mathbf{j=1}}^{\mathbf{N}}|\mathbf{X(i,j)}|^{\mathbf{2}} \bigg/ \sum_{\mathbf{i=1}}^{\mathbf{M}}\sum_{\mathbf{j=1}}^{\mathbf{N}}|\mathbf{\bar{X}(i,j)}|^{\mathbf{2}}$$

4. DARK CHANNEL PRIOR METHOD

Recently, Dark channel prior method (DCPM) was proposed to clear the foggy images [21]. It works on both RGB and grayscale images. This method can be implemented following four steps estimating of the transmission, soft matting, recovering of scene radiance, estimating the atmospheric light. The equation of foggy image is [20]

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

where I is the observed intensity, t is the medium transmission, A is the atmospheric light and J is the scene radiance. DCPM is based on the assumption that at least one color channel has very low intensity at some pixels. For an image J, it can be represented as

$$\boldsymbol{min_{x'\varepsilon\Omega}\left(min_{c\varepsilon\{r,g,b\}}(J_c(x'))\right) \leq \delta}$$

$\mathbf{J}^c$ is a color channel of **J** and **Ω(x)** is a local patch centered at **x**.$\tilde{t}$(x) represents the patch transmission. Taking the min operator in local patch on the foggy image equation:

$$\boldsymbol{min_{y\varepsilon\Omega(x)}I^c(y) = \tilde{t}(x)min_{y\varepsilon\Omega(x)}(J^c(y) + (1 - \tilde{t}(x)))A^c}$$

The min operation is performed on three color channels independently. This above equation becomes:

$$\boldsymbol{min_{y\varepsilon\Omega(x)}\frac{I^c(y)}{A^c(y)} = \tilde{t}(x)min_{y\varepsilon\Omega(x)}(\left(\frac{J^c(y)}{A^c}\right) + (1 - \tilde{t}(x)))}$$

Then take the min operation among three color channels independently.

$$\boldsymbol{min_c(min_{y\varepsilon\Omega(x)}\frac{I^c(y)}{A^c(y)})} \\ = \boldsymbol{\tilde{t}(x)min_c(min_{y\varepsilon\Omega(x)}\left(\frac{J^c(y)}{A^c}\right))} \\ + \boldsymbol{(1-\tilde{t}(x))}$$

According to dark channel prior, the dark channel J^{dark} of fog free radiance J tend to be zero.

$$\boldsymbol{J^{dark} = min_c(min_{y\varepsilon\Omega(x)}(J^c(y)) = 0}$$

As A^c is always positive, this leads to

$$\boldsymbol{min_c\left(min_{y\varepsilon\Omega(x)}\left(\frac{J^c(y)}{A^c}\right)\right) = 0}$$

$$\boldsymbol{\tilde{t}(x) = 1 - min_c(min_{y\epsilon\Omega(x)}\left(\frac{I^c(y)}{A^c}\right))}$$

$\left(\frac{I^c(y)}{A^c}\right)$ provides the estimation of transmission. The soft matting algorithm is used to refine the transmission map obtained.

$$\boldsymbol{E(t) = t^T L t + \lambda(t-\tilde{t})^T(t-\tilde{t})}$$

L is matting Laplacian matrix.
The optimal t can be obtained by solving the following sparse linear system:

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

where U is the identity matrix of same size as L. λ is 10^{-4} taken.
The directly recovered scene radiance is prone to noise. So the transmission t(x) is restricted to lower bound t_0 i.e. small amount of fog is preserved in the case of dense fog images. The final scene radiance J(x) [20] is recovered by:

$$\boldsymbol{J_c(x) = \frac{I_c(x) - A_c}{max\,(t(x), t_0)} + A_c}$$

For estimating the atmospheric light, the pixels with highest intensity are taken as the atmospheric light. So the 0.1% brightest pixels in dark channel are selected for atmospheric light.

5. RESULTS & DISCUSSIONS

To analyze the performance of different methods, both the real RGB foggy images as well as artificially simulated foggy images are used. Adobe Photoshop CS5 is used to add fog to this image. MATLAB R2010a is used for the simulation of results. In this paper, 18 images have been used to analyze performance and effect on only three images is shown in Figure 1 to 3. The four filters i.e.AlphaTrim filter, Anisotropic Diffusion Filter, Guided Filter, Lee filter, Median filter and Wiener filter are simulated. These filters work on gray scale images, so first input image is converted into gray scale foggy image and de-noising is performed. For quantitative comparison, in terms of parameters like signal to noise ratio (SNR), SC, NAE, NCC and mean square error (MSE) are computed. The quantitative results have been shown in Tables 1-4 and Figure 4. Table 1 shows that the results of Median filter are better than the other filters in terms of SNR. Tables 2 and 3, shows that Alpha-trim filter performance is better in terms of metrics MSE and NAE. Table 4 shows that Anisotropic Diffusion filter results in terms of metric SC. As ultimate judge is a human observer, so for visual comparison processed images are shown in Figure 1 to 3. The visual results reveal that output of dark channel method is best among other methods under consideration.

5. CONCLUSION

From the qualitative analysis of the results, it is clear that filters could not enhance the foggy images. The dark channel prior method is best among the implemented techniques in this paper to remove fog from foggy images. In future, more work can be done using other techniques with dark channel prior method

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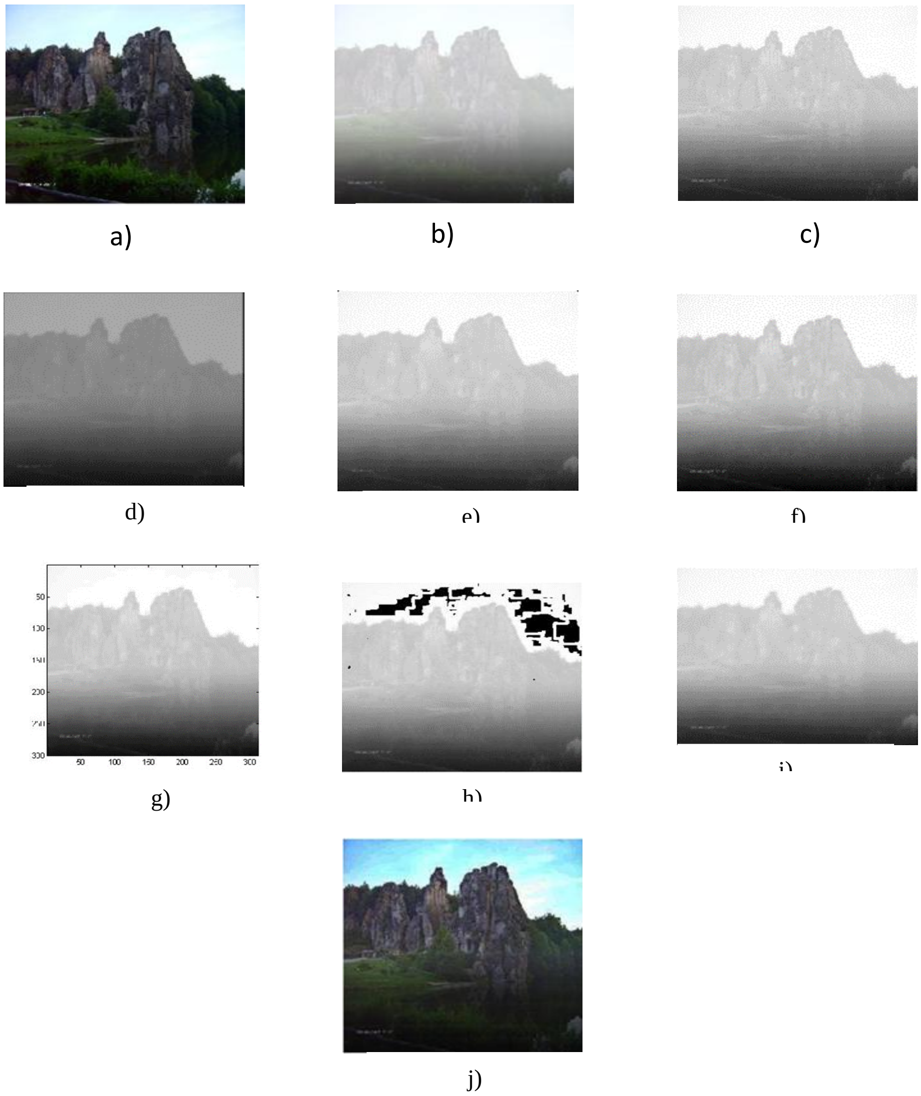


Figure 1: a) Original RGB Image, processed images by b) Foggy RGB image, c) Foggy grayscale image. Results of d) AlphaTrim Filter, e) Median Filter, f) Guided filter, g) Anisotropic Diffusion Filter, h) Lee Filter, i) Wiener Filter and j) Dark channel prior method

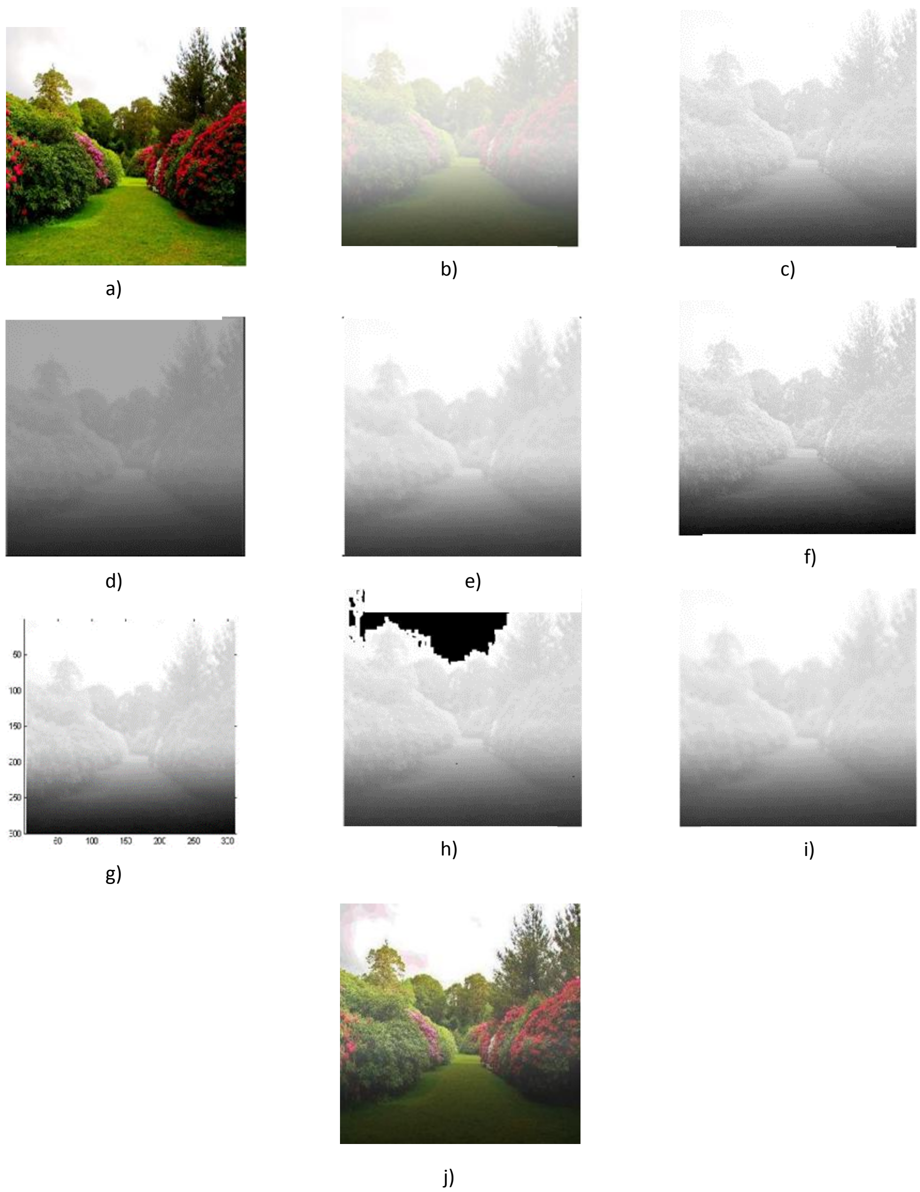


Figure 2: a) Original RGB Image, processed images by b) Foggy RGB image, c) Foggy grayscale image. Results of d) AlphaTrim Filter, e) Median Filter, f) Guided filter, g) Anisotropic Diffusion Filter, h) Lee Filter, i) Wiener Filter and j) Dark channel prior method

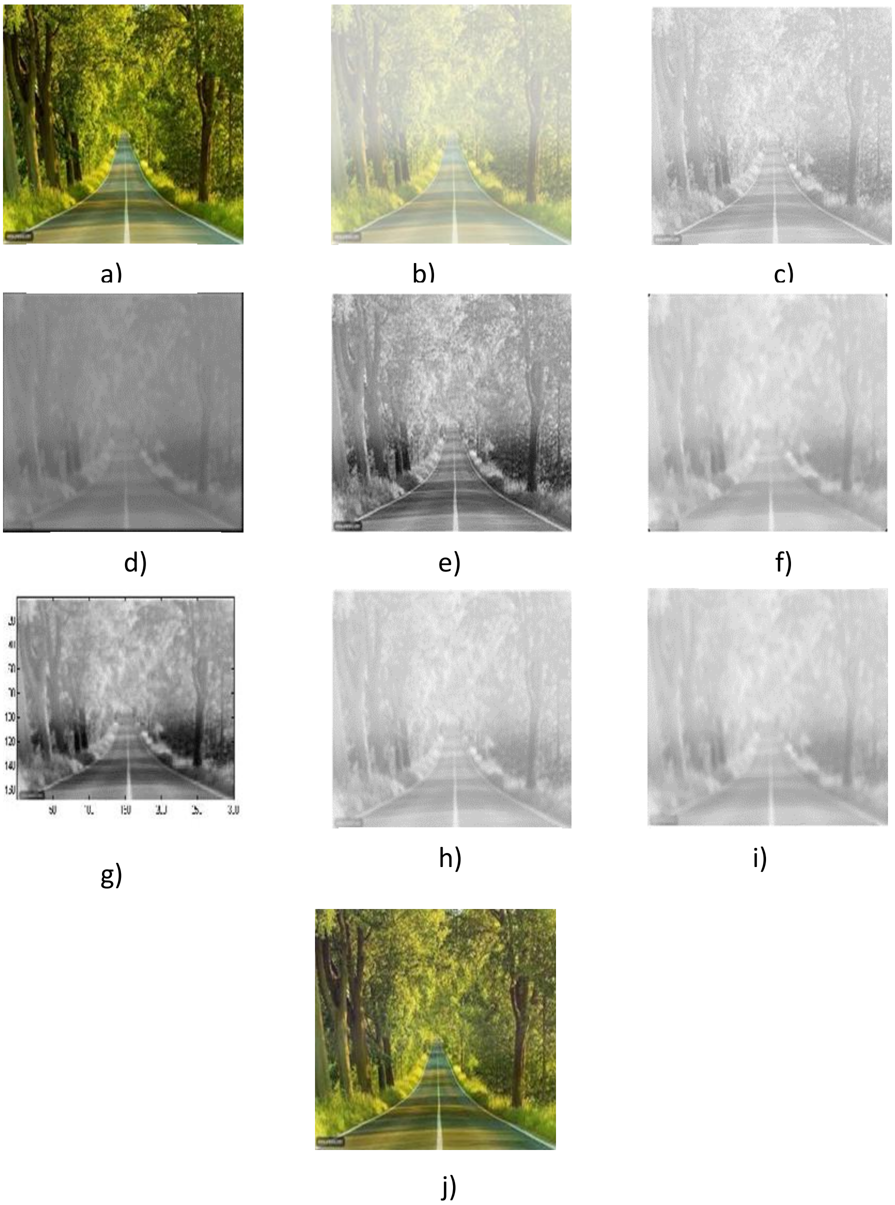


Figure 3: a) Original RGB Image, processed images by b) Foggy RGB image, c) Foggy grayscale image. Results of d) AlphaTrim Filter, e) Median Filter, f) Guided filter, g) Anisotropic Diffusion Filter, h) Lee Filter, i) Wiener Filter and j) Dark channel prior method

Table 1. Performance Comparison of different filters on different foggy images in terms of Signal to Noise Ratio (SNR)

IMAGES	ALPHA TRIM	ANISO TROPIC	GUIDED	LEE	MEDIAN	WIENER
IMAGE 1	4.8821	8.6445	13.344	8.5676	14.1338	**14.2091**
IMAGE 2	5.7136	**8.6686**	6.7986	7.239	7.2088	7.2432
IMAGE 3	6.5499	7.1658	9.6308	8.9802	7.7936	**9.9595**
IMAGE 4	5.7957	7.8091	7.9672	6.2071	10.1225	**10.1251**
IMAGE 5	5.3044	**7.8958**	6.5242	6.8582	6.4146	6.4921
IMAGE 6	2.7762	6.0167	5.6149	6.8204	**8.4929**	6.821

IMAGE 7	4.0537	6.8523	7.6168	**7.8527**	7.785	7.8225
IMAGE 8	6.647	7.1155	8.5298	1.157	**20.3897**	4.3441
IMAGE 9	3.0258	7.4417	8.4068	**9.9512**	8.4515	9.0722
IMAGE 10	4.7656	7.6004	8.1746	8.9804	9.5673	**10.1622**
IMAGE 11	6.6433	8.0375	7.9438	12.0311	**17.2112**	16.3079
IMAGE 12	3.0561	6.5932	6.2716	**7.4077**	7.309	7.3758
IMAGE 13	2.8101	7.2934	6.8747	4.6473	**8.0831**	7.8117
IMAGE 14	1.8246	5.9742	5.8171	5.2159	6.5866	**6.5994**
IMAGE 15	2.9858	5.6018	5.2338	5.8939	**5.9633**	5.8362
IMAGE 16	2.6355	**4.283**	3.6823	3.9704	4.0553	3.9934
IMAGE 17	3.138	5.6392	13.8224	8.0314	**15.0164**	14.9403
IMAGE 18	2.5619	6.8303	6.3603	4.3088	**7.293**	7.2915

Table 2. Performance Comparison of different filters on different foggy images on the basis of Mean Square Error (MSE)

IMAGES	ALPHA TRIM	ANISO TROPIC	GUIDED	LEE	MEDIAN	WIENER
IMAGE 1	**6336.8**	15683	12019	15782	12778	12943
IMAGE 2	**8584.1**	24099	18129	19855	19838	19881
IMAGE 3	**8829.9**	26792	20750	20844	21911	22254
IMAGE 4	**4365.1**	17156	14063	11870	14826	14849
IMAGE 5	**10926**	26049	24389	24834	25155	25344
IMAGE 6	**2318.7**	9350.9	5898	6771.1	6788.1	6841.6
IMAGE 7	**3476.6**	12145	7816.7	7496.2	7413.8	7648.8
IMAGE 8	**3484.4**	9190.3	5175	12861	12703	12718
IMAGE 9	**2446.3**	10435	6879.6	6941.6	6923.5	6986.1
IMAGE 10	**3911.2**	28625	9128.6	10066	9343	9171
IMAGE 11	**3711.3**	14000	9367.8	14806	14627	14531
IMAGE 12	**3831.9**	10995	8217.3	8058.2	8349.3	7975.5
IMAGE 13	**6636.4**	14282	12509	21635	13225	13254
IMAGE 14	**3741.6**	8226.5	5892.2	8468.2	5572.6	5537.2

IMAGE 15	**5700.4**	13964	10433	10840	11052	10984
IMAGE 16	**4783.7**	10213	8271.4	8099.8	8157.5	8177.8
IMAGE 17	**2012.1**	6903.9	5449.8	12458	6091.2	6002.4
IMAGE 18	**2184.8**	8422.7	6412.4	11127	6159.2	6219.6

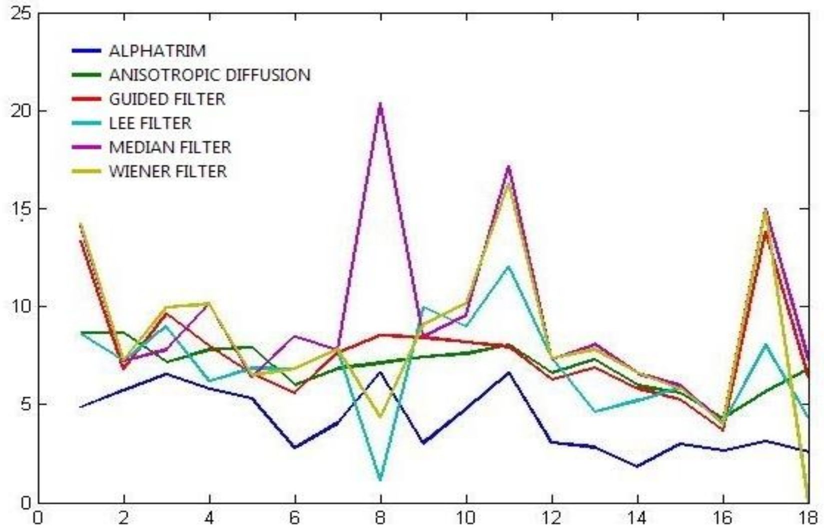
Table 3. Performance Comparison of different filters on different foggy images in terms of Normalized Absolute Error (NAE)

IMAGES	ALPHA TRIM	ANISO TROPIC	GUIDED	LEE	MEDIAN	WIENER
IMAGE 1	**0.7645**	1.07	0.9548	1.1405	1.015	1.0234
IMAGE 2	**1.3127**	2.2138	1.8813	1.9426	1.9419	1.9446
IMAGE 3	**1.6989**	2.9367	2.5732	2.5859	2.7018	2.7168
IMAGE 4	**0.5927**	1.238	1.105	1.025	1.1499	1.1504
IMAGE 5	**1.5279**	2.3536	2.2783	2.2686	2.2989	2.307
IMAGE 6	**0.2703**	0.6064	0.4776	0.4976	0.4961	0.499
IMAGE 7	**0.4954**	0.9656	0.8022	0.7904	0.7839	0.7957
IMAGE 8	**0.4939**	0.8288	0.5915	1.0814	1.0764	1.0809
IMAGE 9	**0.3197**	0.7013	0.5733	0.575	0.575	0.5763
IMAGE10	**1.0475**	2.9277	1.6463	1.7408	1.6792	1.6662
IMAGE11	**0.4742**	1.0049	0.7796	1.1054	1.0986	1.0965
IMAGE12	**0.3953**	0.7151	0.6204	0.617	0.6273	0.6138
IMAGE13	**0.6456**	0.8301	0.773	1.0641	0.7764	0.7785
IMAGE14	**0.3048**	0.4948	0.4233	0.4848	0.4087	0.4076
IMAGE15	**0.5364**	0.8339	0.6917	0.7046	0.7104	0.7093
IMAGE16	**0.4553**	0.6518	0.5701	0.5491	0.552	0.5527
IMAGE17	**0.2245**	0.4391	0.4019	0.5917	0.4295	0.4261
IMAGE18	**0.267**	0.5895	0.5244	0.6479	0.5024	0.5049

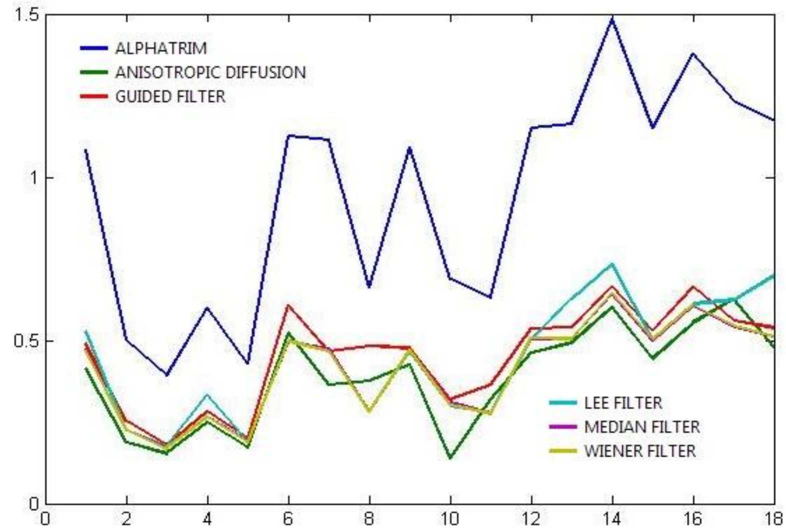
Table 4. Performance Comparison of different filters on different foggy images in terms of Structural Content

IMAGES	ALPHA TRIM	ANISO TROPIC	GUIDED	LEE	MEDIAN	WIENER
IMAGE 1	1.0824	**0.4123**	0.491	0.528	0.4718	0.4687
IMAGE 2	0.501	**0.187**	0.252	0.2248	0.2253	0.2248

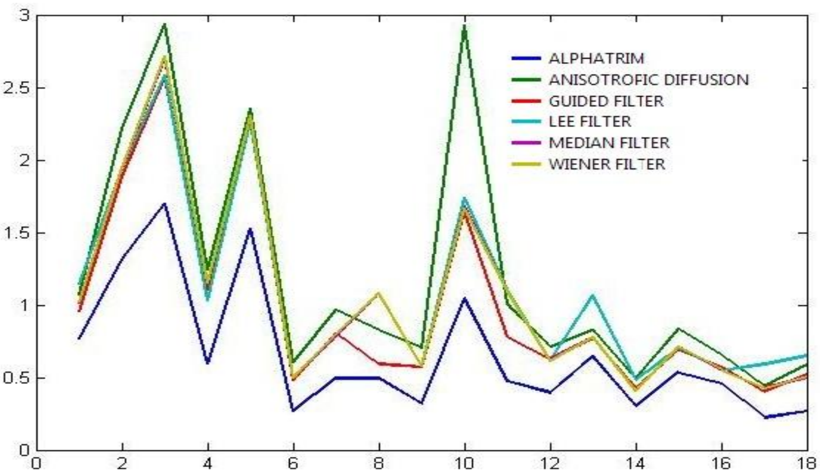
IMAGE 3	0.3928	**0.1535**	0.1804	0.1779	0.1727	0.1697
IMAGE 4	0.5987	**0.2502**	0.2809	0.3337	0.2646	0.2647
IMAGE 5	0.4263	**0.1713**	0.1989	0.1886	0.1897	0.1878
IMAGE 6	1.1262	0.523	0.6079	0.4969	**0.4952**	0.4971
IMAGE 7	1.1146	**0.3636**	0.4668	0.4678	0.4749	0.4673
IMAGE 8	0.6625	0.3753	0.4824	**0.2805**	0.281	0.2815
IMAGE 9	1.0923	**0.427**	0.4765	0.4656	0.4716	0.4695
IMAGE 10	0.6865	**0.1381**	0.3212	0.2993	0.3097	0.3028
IMAGE 11	0.6327	0.3196	0.3644	0.2772	**0.2754**	0.276
IMAGE 12	1.151	0.4629	0.5355	**0.5038**	0.5047	0.5069
IMAGE 13	1.1626	**0.4931**	0.54	0.6272	0.5043	0.5046
IMAGE 14	1.4841	**0.6005**	0.6655	0.7335	0.6416	0.6449
IMAGE 15	1.1512	**0.4439**	0.5304	0.503	0.4978	0.5046
IMAGE 16	1.3779	**0.554**	0.6625	0.6116	0.6057	0.6084
IMAGE 17	1.2337	0.6267	0.5614	0.623	**0.5409**	0.5432
IMAGE 18	1.1717	**0.4778**	0.5373	0.6976	0.5123	0.5114



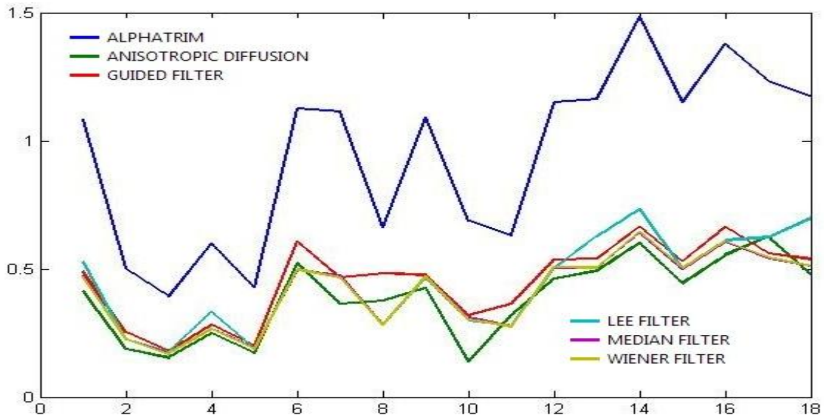
a) Comparison of various filters using SNR.



b) Comparison of various filters using NAE.



c) Comparison of various filters using MSE



d) Comparison of various filters using SC

Figure 4: shows all quality measure values for the 18 images taken for analyzing of the results