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A REVIEW ON COMPARATIVE ANALYSIS OF DEHAZING OF REMOTE SENSING IMAGES USING DIFFERENT FILTERS

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Abstract

Haze is an atmospheric phenomenon caused by scattering of atmospheric particles in air and these factor causes deterioration of images, captured by the sensors. Haze detection, removal and enhancement of dehazed images are extremely important for the analysis and interpretation of Remote sensing images. This work presents the comparison of haze removal methodologies and analysis of dehazed images in terms of its image quality metrics. Consequently various imaging filters are employed to enhance fine details in the dehazed images and comparative analysis is presented. Simulation results reveal that the filter enhancement technique produces images with better quality and visible improvements in Quality metrics.

Keywords:

Remote Sensing, Haze Removal, Adaptive Dehazing, Deformed Haze Imaging Model, Dark Channel Prior, Dark Channel Saturation Prior, Image Filters

1. INTRODUCTION

The physical characteristics of a geographical location is detected and monitored with the help of remote sensing. The characteristics are measured by radiance at a particular distance from the capturing sensor. Remote sensing images finds application in various fields such as updating road map in transportation, urban planning, crop analysis in agriculture, resource management, coastal mapping, damage assessment after calamity, meteorological weather monitoring, classification of land cover, Bio diversity monitoring etc.

As the distance between the sensor and the scene being captured, is vast, there is a chance for the particles such as haze, fog, smoke, mist and aerosol particles to get accumulated in the line of sight. They also cause scattering of light by a phenomenon called scattering multiplicity. It can densely affect the quality of the image, by causing image degradation and loss of details in image. So, subsequent analysis and interpretation from the remote sensing image is also affected.

Hence there is a need for the elimination of haze and noise removal from the image by applying haze removal techniques. Dehazing can be achieved through the single image dehazing and multiple image dehazing. Yet single image dehazing is a risky and tedious process as only a single hazy image is available.

He at al. [4] proposed a traditional prior based technique called dark channel prior which states that, in non-sky patches, some pixel has zero intensity value in any one of the color channels. Using haze imaging model along with DCP, yields estimation of depth and transmission. Even though it is simple and powerful, it fails and become invalid in cases such as when the scene objects being captured is similar to global atmospheric light and no shadow is fallen on them. Under such situations, this method tends to under estimate the transmission values.

Rizal Mutaqin et al. [8] proposed a method of dehazing to remove haze contents from the image by employing guided filter which considers input image as the guidance image. Guided filter usually performs better and fast depending on the kernel size and range of intensity values. It smoothen the texture of image and also preserving the edge information. The derivation of guided filter is the fast guided filter. Both the algorithms are identical to each other except the additional feature of sub-sample and unsample are used in fast guided filter to improve the contrast with predefined resolution factor.

Diana et al. [7] reviewed the performance metrics by assessing the quality of edges. Some of the commonly used image quality metrics are MSE, PSNR and SSIM. But these methods do not justify the quality of the image by considering edge preservation. Some of the edge aware performance metrics are EBIQA, ESSIM, GCMSE, NSER etc. These metrics provides values close to the acceptance of human visual assessment.

Improvement in single image dehazing has been done by employing techniques of DCP [2] and Multi Scale Retinex (MSR) algorithms [1]. Transmission is estimated based on the luminance component and the above methods performs much better without user interaction [12]. Enhancement of remote sensing images is done by employing regularized histogram equalization and discrete cosine transform (DCT) [11].

RGB image is converted to HSV image followed by separation of the image into 3 different bands namely H, S and V. Saturation is increased in S band and Adaptive histogram equalization is applied to V band. Finally 3 bands are combined together to obtain HSV dehazed image and gamma correction is linearized [6].

2. EXISTING METHOD

2.1 HAZE IMAGING MODEL

Haze imaging model is the representation of formation of hazy images. Hazy images are formed when the light is scattered by particulate matter such as aerosol, fog, mist, gaseous pollutants in molecular form, etc. causing visibility problems and resulting in degradation of image. The mathematical equation describing haze imaging model is given as

$$I(x) = J(x)t(x) + A(1-t(x)) \quad (1)$$

where, $I(x)$ is the hazy image captured by the sensor, $J(x)$ is the scene radiance, A is the global air light and $t(x)$ is the transmission medium. From a single known data of $I(x)$, 3 unknowns namely $J(x)$, $T(x)$ and A has to be calculated. Dark channel prior is used to estimate the unknown parameters.

2.1.1 Dark Channel Prior:

He at al. [3] proposed traditional algorithm for dehazing called Dark Channel Prior. It exploits the properties of dark pixels, having zero intensity values in at least one of the color channels except the sky portions [4]. On the basis of above observations, DCP is represented as

$$J^{dark}(x) = \min_{c\in(r,g,b)}\left(\min_{y\in\Omega(x)} J^{c}\left(y\right)\right) \tag{2}$$

$$J^{dark} = 0 \tag{3}$$

where, $J^{dark}(x)$ is the dark channel of the given image. $J^{c}(y)$ is the color channel of J, $\Omega(x)$ is the local patch with its center located at x. The value of J^{dark} is approximated to zero, which is called as dark channel prior. This low or zero intensity might be due to (i) cast of shadow (ii) vibrant or colorful objects (iii) dark surfaces or object.

2.1.2 Atmospheric Light Estimation:

Atmospheric light is the function of product of luminance and inverse of depth map. Luminance is defined as the total amount of light emitted by a scene object per unit area and also it denotes the brightness. Depth map is an image that contains information relating to distance between the object and the sensor. Atmospheric light can be predicted accurately by choosing the top 0.1% brightest pixels from the dark channel of an image. Patch size should be large enough to estimate the air quality effectively and to avoid inaccurate finding.

2.1.3 Estimation of Transmission:

Transmission medium refers to the part of light that is not scattered and reaches the sensor directly. High values (dark) of the transmission medium indicates the presence of haze and low values (lighter) of the transmission medium indicates the haze less region. Transmission is mathematically expressed as

$$t(x) = e^{-\beta d(x)} \tag{4}$$

The above equation implies that the transmission is dependent upon 2 factors namely

- Scattering co-efficient (β).
- Distance between the object and the observer ($d(x)$).

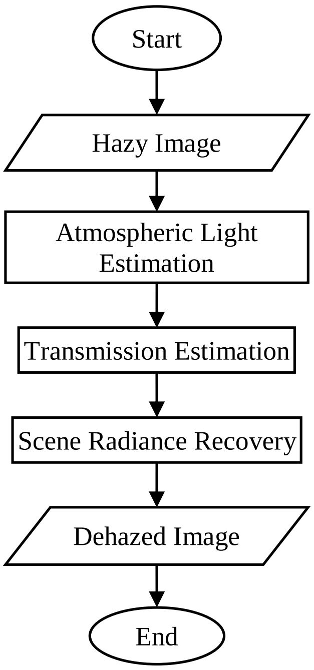


Fig 1. Flow of image dehazing

Scattering co-efficient has a positive correlation with haze turbidity (T) and negative correlation with wavelength (λ). Also if the size of the particles scattering the light is larger than the wavelength and hence the wavelength can be neglected. In an atmosphere with clear weather condition with no scattering of light, the value of β becomes zero, making the transmission unity and hence observed image $I(x)$ becomes equal to radiance to be recovered ($J(x)$). To achieve improvement in accuracy of transmission map, it might be necessary to apply either matting technique or employing detail enhancement filters.

2.1.4 Scene Radiance:

After estimating air light (A) and transmission ($t(x)$), radiance is recovered according to the following equation,

$$J\left(x\right) = \frac{I\left(x\right) - A}{\max\left(t\left(x\right), t_0\right)} + A \tag{5}$$

If transmission value is close to zero, there is a possibility for the noise to get accumulated. So, transmission is limited to the lower bound of transmission value t_0=0.1.

3. WORKFLOW OF PROPOSED SYSTEM

The modified work has 3 phases namely, haze assessment to assess the degree of haze, haze removal to eliminate haze in an image and enhancement of dehazed image after haze removal. The flow of modified work is depicted in the Fig.2 with a flow chart,

3.1 HAZE ASSESSMENT

Assessment of haze helps in filtering out the haze from the image by determining the location and the amount of haze present in the image. This is a 2 step framework consisting of (i) formulation of haze distribution map and (ii) determination of degree of haze in a numerical form by using a mathematical assessment metric [10].

3.1.1 Haze Distribution Map:

Maximum gap value between 3 color channels of an image is said to be range channel of an image.

$$I^{range}\left(x\right) = \max_{c\in(r,g,b)} I^{c}\left(x\right) - \min_{c\in(r,g,b)} I^{c}\left(x\right) \tag{6}$$

where $X = (x,y)$ is the co-ordinates of pixel, I is observed image, I_c represents the color channel of observed image I. Minimum pixel intensity in a hazy patch is larger than that in haze less patch. Hence minimum intensity can affect the HDM. Initially, hazy image is normalized to [0,1], represented as I_N. HDM is defined as

$$H(\mathrm{x}) = \min_{c\in(r,g,b)} I_N^{c}\left(x\right) \tag{7}$$

According to DCP, the minimum intensity of haze free region should be zero. But, raw HDM tends to produce some higher intensity values in haze free region, which is undesirable. So, raw HDM has to be corrected by applying the concept of saturation. To achieve an accurate HDM, saturation values are subtracted from the raw HDM.

$$\tilde{H}_s\left(x\right) = \max(H(x) - \alpha S(x), 0) \tag{8}$$

$$S(x) = 1 - \frac{3\min\big(R(x), G(x), B(x)\big)}{R(x) + G(x) + B(x)} \tag{9}$$

where *R*, *G*, *B* represents the color channels of image, α denotes the adjusting parameter for making non zero values of haze free regions to zero.

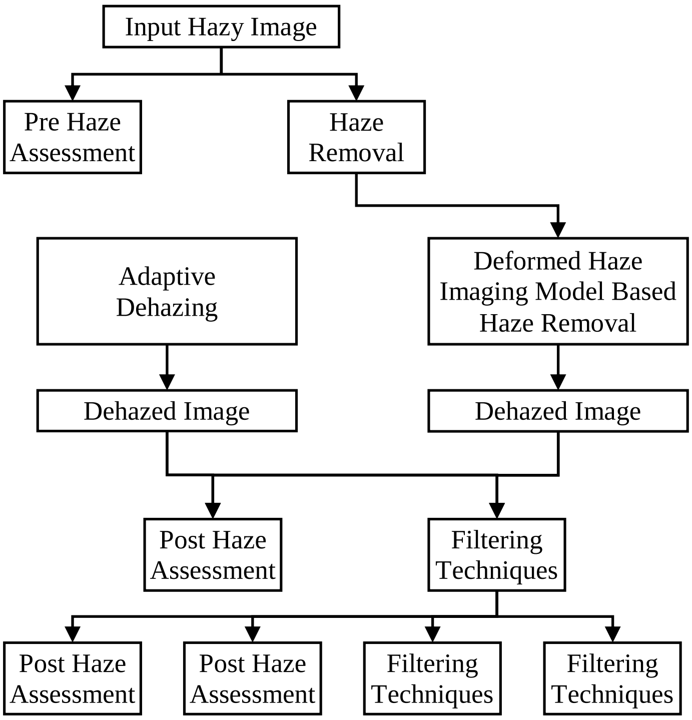


Fig.2. Flow of Proposed Work

3.1.2 HDMHA:

The degradation of image quality is dependent on the thickness of haze and its coverage area. A metric proposed by Pan et al. [] calculates the degree of haze, which is called as HDM based Haze Assessment. Initially the image is divided into non overlapping patches. Size of patches plays an important role in the accuracy of results. Smaller the size of patch, higher the accuracy would be.

$$HDMHA_i = \frac{2\min\limits_{y\in\Omega(x)} H_S(y)}{\max\left(T, \max\limits_{y\in\Omega(x)} H_S(y) + \min\limits_{y\in\Omega(x)} H_S(y)\right)} \tag{10}$$

where, $\Omega(x)$ is the patch having its center at *x*. *T* is the haze turbidity parameter. Its value is fixed to 0.8. Accuracy and time can be balanced by replacing minimum operator by mean operator.

$$HDMHA_i = \frac{2\,\mathrm{mean}_{y\in\Omega(x)} H_S(y)}{\max\left(T, \max\limits_{y\in\Omega(x)} H_S(y) + \min\limits_{y\in\Omega(x)} H_S(y)\right)} \tag{11}$$

For the entire image, metrics of all the patches are summed up to produce the HDMHA.

$$HDMHA = \frac{1}{n}\sum_{i=1}^{n} HDMHA_i \tag{12}$$

Higher value of HDMHA indicates huge amount of haze and lower value of HDMHA indicates milder spread of haze.

3.2 ADAPTIVE DEHAZING

Dark channel prior works effectively on outdoor images according to He et al. [3]. But, it does not works well on remote sensing images due to large imaging distance which results in weakening of brightness due to turbid medium existing between the scene objects and the capturing point of view. The prior used in adaptive dehazing is called dark-channel saturation prior, which is explained in the below section.

3.2.1 Dark Channel Saturation Prior:

Saturation denotes the purity of a color, also called as chroma. Maximum saturation value of the pixels is said to be the saturation of a patch.

$$J^s(x) = W * \max_{y\in\Omega(x)} S(y) \tag{13}$$

$$S(y) = 1 - \frac{3\min\limits_{c\in(r,g,b)} J^c(y)}{J^r(y) + J^g(y) + J^b(y)} \tag{14}$$

where, *W* represents the intensity of levels of an image (*W* = 255). *Jr*(*y*), *Jg*(*y*), *Jb*(*y*) are the 3 color channels of pixel *y* in an image.

For a haze less patch, saturation (purity) will be higher, leading to the visibility of vibrant color information and the value of dark channel will be lower. On the contrary, for a hazy patch, saturation will be lower and intensity values of dark channel will be higher. Each pixel in a patch decides the values of both the saturation and dark channel. The 2 features namely saturation and dark channel are complementary to each other. Dark channel saturation prior is mathematically represented as

$$J_{ds}(x) = \max(J_d(x) - J_s(x), 0) \tag{15}$$

Saturation map is used to correct the non-zero values of dark channel of remote sensing values to zero. Maximum operator is used to neglect negative values.

$$\begin{aligned} J'^{ds}(x) = \min_{y\in\Omega(x)} &\left(\frac{\min\limits_{c\in(r,g,b)} I^c(y) + A_0 t(\tilde{y}) - A_0}{t(\tilde{y})}\right) \\ &+ W\,\frac{3\min\limits_{c\in(r,g,b)} I^c(y) + A_0 t(\tilde{y}) - A_0}{W_I(y) + 3\big(A_0 t(\tilde{y}) - A_0\big)} - W \end{aligned} \tag{16}$$

$$W_I(y) = I^r(y) + I^g(y) + I^b(y)$$

where, W_I defines the sum of three color channels *r*, *g*, *b*.

3.3 DEFORMED HAZE IMAGING MODEL

Deformed haze imaging model is developed by comparing the statistical features of outdoor images and remote sensing images [9]. The average intensity value of outdoor images is equal to zero. The average intensity value of remote sensing is low, but not equal to zero.

The gap between the origin and minimum intensity value of remote sensing images is assumed to be translational term, denoted by *C*. *C* is very significant and cannot be neglected. In order to bring the average intensity to zero, the difference translational term *C* has to get subtracted from the terms of haze imaging model.

$$I(x)\text{-}C(t(x))=J(x)t(x)+A(1\text{-}t(x)\text{-}C(t(x)) \quad (17)$$

$$I(x)\text{-}C(t(x))=(J(x)\text{-}C)t(x)+A(1\text{-}t(x)) \quad (18)$$

The value of translational term has to be derived from the statistical features of haze less images. By including the translational term C in dark channel equation and exploiting deformed haze imaging model, transmission is obtained as follows.

$$t(x)=\frac{A_0-\min_{y\in\Omega(x)}\left(J'^{ds}(x)=\min_{y\in\Omega(x)}\left(\min_{c\in(r,g,b)}I^c(y)\right)\right)}{A_0-C} \quad (19)$$

The main objective of the parameter C is to eliminate the deviations produced when DCP is applied directly to remote sensing images and make the DCP suitable for remote sensing images as like outdoor images.

3.4 IMAGE ENHANCEMENT FILTERS

To improve the interpretability of information from images, it is necessary to enhance the images. Some of the enhancement techniques are filtering, histogram equalization, slicing, contrast stretching etc. Some of the filters are implemented to improve the quality of images.

3.4.1 Guided Filter:

Guided filter is used as smoothing filter, which performs edge-preservation [5]. It can also filter noise by retaining sharpness of the image. Guided filter calculates the output by using the contents present in the guidance image. The guidance image can be the same input image or any different image. Guided filter works only on a condition that linearity exists between guidance image (I) and the filtered output (q).

The main advantage of guided filter is that the linear complexity of O(1) which does not involve much mathematical computation and performs fast and accurate. It is used in feathering/matting and haze removal. The guided filter has the following properties,

- Edge preservation property
- Gradient preservation property
- Structure transferring property

3.4.2 Gaussian Filter:

High pass filters are used for edge detection and image sharpening. High pass filters can emphasize finer details in the image. High pass image is added to the original image to get the sharper image. 2-D Gaussian filter is given by

$$G(x,y)=\frac{1}{2\pi\sigma^2}e^{-\frac{(x^2+y^2)}{2\sigma^2}} \quad (20)$$

where σ is the standard deviation, which also denotes the degree of smoothing. Gaussian filtered images can be easily correlated with the Fourier spectrum of the image. If the Fourier spectrum has more whiteness, amount of blurring is lower because most source pixels are unaltered during the convolution filter.

3.4.3 Non Local Means Imaging Filter:

NLM filters are used for image denoising. The filter takes mean value of all pixels in the image, weighted by how similar these pixels are, to the target pixel. It is a non-iterative edge-preserving filter used for denoising images, which are degraded by additive white Gaussian noise. It provides better post filtering clarity and contributes only less loss in details of the image.

$$NLM(u_j) = \sum_{k\in SW_j} W_{jk}(u)\cdot u_k \quad (21)$$

where, SW_j represents search window, k is the pixel index, u is the image to be preserved, $W_{jk}(u)$ is the weighing co-efficient. NLM filter computes the similarity based on patches rather than on pixels. Patch is generally taken in squared region with a center pixel. The relation of similarity between the pixels j and k is dependent on Euclidean distance of the patches.

3.4.4 Laplacian Filter:

It is a 2-D isotropic measure of second derivative (spatial) of an image. The term isotropic denotes that all the operations are carried out equally in all directions without sensitivity or bias towards a particular direction. It is a kind of derivative filter which enhances the region of rapid intensity changes in the images.

$$L(x,y) = \frac{\partial^2 I}{\partial x^2}+\frac{\partial^2 I}{\partial y^2} \quad (22)$$

The above equation is implemented using convolution filter.

3.5 IMAGE QUALITY METRICS

Image quality can get degraded during image acquisition and processing. There are 3 no reference image quality metrics to analyze the quality of remote sensing images. They are explained below,

3.5.1 NIQE:

NIQE is a blind image quality analyzer that considers the measurable deviations from regularities in statistical features of natural images. It is based on the construction of quality aware collection of statistical features. Lower values of NIQE indicate better perceived quality. It is calculated using the below inbuilt command in Matlab.

$$Score = niqe(A) \quad (23)$$

where A is the input image and *Score* gives the NIQE value.

3.5.2 PIQE:

PIQE evaluates the no-reference quality score of an image through block wise distortion estimation. The syntax for calculating PIQE of an image is given by

$$Score = piqe(A) \quad (24)$$

where A is the input image and *Score* gives the PIQE value.

Table.1. PIQE range

Quality scale	Score range
Excellent	[0,20]
Good	[21,35]
Fair	[36,50]
Poor	[51,80]
Bad	[81,100]

3.5.3 BRISQUE:

Blind/Reference less Image Spatial Image Quality Evaluator is a natural scene statistic based image quality assessment (IQA) model which operates in the spatial domain. The lower the values of the image quality metric, the higher the perceptual quality of the image and denotes reduced degradations.

$$Score = \text{brisque}(A) \quad (25)$$

where A is the input image and $Score$ gives the PIQE value.

3.5.4 Entropy:

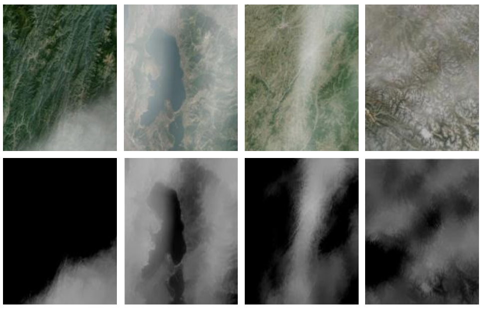
Entropy is a measure of information content in an image, which is denoted as the average uncertainty of information source. In Image, Entropy is defined as various states of intensity level, which the individual pixels can adapt. It is employed in the quantitative analysis and evaluation of image details, the entropy value is used as it provides better comparison of the image details.

3.5.5 Edge Preservation Index (EPI):

In the context of image, edge preservation refers to the ability of the filter to enhance the image, simultaneously retaining the edge information and does edge enhancement too. Some of the filters performing edge preservation are median, guided, bilateral, anisotropic diffusion filters etc.

4. EXPERIMENTAL RESULTS AND DISCUSSION

In this section, the dehazing results of 2 techniques namely Haze removal based on deformed haze imaging model and adaptive haze removal techniques are compared with each other. Also haze density is measured and HDMHA is evaluated to know the position of haze. The Fig.2 shows the distribution of haze in an image and the mathematical metric called HDMHA. From Fig.3(a) implies input hazy images, Fig.3(b) shows the removal of haze based on deformed haze imaging model and Fig.3(c) shows the adaptive haze removal.



0.1504 0.7040 0.3455 0.4785

Fig.2. HDM and HDMHA

(a) (b) (c) (d)

(e) (f) (g) (h)

(i) (j) (k) (l)

Fig.3. Dehazing results (a)-(d) input hazy images (e)-(h) deformed haze imaging model based haze removal (i)-(l) adaptive haze removal

Table.2(a). Image Quality Metrics of Haze Removal Based on Deformed Haze Imaging Model

Dehazed Image	NIQE	PIQE	BRISQUE	Entropy	EPI
e	4.4094	25.3125	46.3280	4.7670	0.5184
f	3.0465	22.5988	35.5172	5.0970	0.4794
g	3.9729	22.2687	46.4793	4.9522	0.5138
h	4.0984	22.3896	46.4793	5.1399	0.5256

Table.2(b). Image Quality Metrics of Adaptive Haze Removal

Dehazed Image	NIQE	PIQE	BRISQUE	Entropy	EPI
i	4.8802	27.4744	44.4744	4.8792	0.5262
j	3.8120	21.0075	34.3693	5.0821	0.4733
k	4.2264	32.3013	42.9863	4.9187	0.4985
l	5.4488	40.9237	42.8376	5.1399	0.5343

In the above Table.2(a) denotes the quality metrics of dehazed images obtained by employing the technique of deformed haze imaging model and Table.2(b) denotes the dehazed images obtained by the technique of adaptive dehazing method. NIQE and PIQE values are reduced in former technique which implies better scene restoration. BRISQUE values do not vary much and is comparable. Entropy and Edge Preservation Index (EPI) indices are also greater in deformed haze imaging model based haze removal. So it can be clearly inferred that the former technique performs better than adaptive haze removal technique. The proposed method attempts to improve the quality of image obtained from deformed haze imaging model by applying various filtering techniques like Gaussian filter, Laplacian filter, non-local means imaging filter and guided filter. The results of the dehazed images after filtering are listed below along with the tabulations of quality metrics, edge and entropy information.

(a) (b) (c) (d)

Fig.4. Laplacian filtered dehazed images

Table.3. Image quality metrics of Laplacian filtered images

Input	NIQE	PIQE	BRISQUE	Entropy	EPI
a	6.6073	43.8124	45.2192	4.8971	0.5212
b	3.4598	24.7775	39.1962	5.1724	0.4911

c	5.2911	41.0866	46.4117	5.0269	0.5129
d	5.2484	33.1982	44.9437	5.2464	0.5600

(a) (b) (c) (d)

Fig.5. Non local means imaging filtered dehazed images

Table 4. Image quality metrics of non-local means imaging filtered image

Input	NIQE	PIQE	BRISQUE	Entropy	EPI
a	4.3838	25.5645	46.2479	4.7669	0.5047
b	3.1800	22.6863	35.5987	5.0807	0.4732
c	3.9694	22.2706	46.4563	4.9521	0.4906
d	4.2043	22.8992	46.7105	5.1286	0.5258

(a) (b) (c) (d)

Fig.6. Guided filtered dehazed images

Table.5. Image quality metrics of guided filtered filter

Input	NIQE	PIQE	BRISQUE	ENTROPY	EPI
a	5.5522	43.3188	43.0567	4.8353	0.4855
b	4.9923	58.0731	45.9772	5.1596	0.4760
c	4.8216	54.0147	42.2585	5.0732	0.5036
d	3.9317	30.9838	37.1056	5.0993	0.4687

(a) (b) (c) (d)

Fig.7. Gaussian high pass filtered dehazed images

Table.6. Image quality metrics of Gaussian high pass filtered images

Input	NIQE	PIQE	BRISQUE	Entropy	EPI
a	7.6587	51.5309	51.3209	3.3747	0.5369
b	4.8974	33.4039	50.4095	3.6326	0.4975
c	6.4362	50.2567	50.8230	3.4496	0.5249
d	7.0022	46.4104	49.8665	3.7352	0.5710

(a) (b) (c) (d)

Fig.8. Gaussian low pass filtered dehazed images

Table.7. Image quality metrics of Gaussian low pass filtered images

Input	NIQE	PIQE	BRISQUE	ENTROPY	EPI
a	4.0887	18.4198	44.2700	4.8150	0.5003
b	3.1047	22.5900	34.9678	5.1428	0.4632
c	4.2995	18.7988	44.9518	5.0153	0.4701
d	4.2762	18.0954	44.7975	501597	0.4972

The filters namely laplacian filter, non-local means image filter, guided filter, Gaussian high pass and low pass filters have been employed to improve the image quality and clarity of the results obtained from deformed haze imaging model based haze removal technique. The inferences are discussed as follows.

From Table.4-Table.6, the Gaussian low pass filter performs much better in terms of its quality metric namely NIQE, PIQE and BRISQUE, showing visible improvements and Non local means imaging filters provide comparable results in NIQE, PIQE and BRISQUE. As shown in Table.4, Table.6 and Table.8, Entropy information is enhanced in 3 filters namely Laplacian, guided and Gaussian low pass filter. Edge and contrast enhancement is needed to portray sharp intensity changes, which is achieved with the help of Laplacian filter and Gaussian high pass filter, shown in Table.6. Depending upon the application and the type of image, filters can be appropriately employed to have better visual clarity and image properties.

5. CONCLUSION

Haze elimination and correction has become inseparable part of image processing and computer vision application. In this work two haze removal methodologies namely adaptive haze removal and deformed haze imaging model based haze removal have been compared and deformed haze image model based haze removal proves to be the better by analyzing the obtained results. And various filters have been applied on dehazed images to enhance the dehazed images and comparative analysis on the filters are provided on examining quality metrics such as NIQE, PIQE, BRISQUE, entropy and EPI from the results achieved.

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