Dehazing of Natural Images UsingVolterra Based Non-Linear Filter

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***Abstract*— When outdoor images are captured by a camera in bad weather conditions which yield poor visibility conditions, where noise is also present due to low contrast of an image, color variation which is a major issue for most computer vision applications. The hazy weather conditions, it blocks the dispersal of haze, smoke and other pollutions in the environment which leads to harm in visibility and respiratory health problems. In this paper, we proposed a Volterra based Non-Linear filters for image enhancement and image restoration in bad weather conditions. The linear filters help to reduce noise but it causes blurriness in the edges of the image. In case of Non-linear filters are dealing with impulsive noise which helps to preserve the edges of the image. So, the Volterra filter is designed to enhance the compact between unwanted noise reduction and edge preservation.**

Keywords—Volterra Filter, De-hazing, Histogram, SSIM,PSNR and MSE

I. Introduction

Under bad weather conditions such as fog, mist, haze which degrade the quality of images due to impact of unwanted particles in the atmosphere. Therefore it is important for computer vision systems to improve the visual effect of the image which highlight the special features of the image. The development of image de-hazing methods is very favorable to many real-world applications, including video assisted transportation, outdoor video surveillance, analysis of remote sensing imagery etc[1]. Volterra filter is recognized one of the non-linear filter which helps to remove the haziness in the image by preserving the edges.

II. Literature review

A. Atmospheric Scattering Model

When the images are captured from the outdoor environment under poor atmospheric conditions, the perceptibility of the scene is prostrate to degradation[2]. This method achieves the interaction of light with the unwanted particles in the atmosphere such as scattering, absorption, and emission which results in poor contrast, washed out colors and low dispersion in the image[3]. When there is a scattering in the atmosphere, there are two phenomenon exist attenuation and air-light which results that the light coming to the camera or observer from the scene gets dissipated due to scattering through water droplet or any other dust particles which degrade the image quality in outdoor scenes[4].

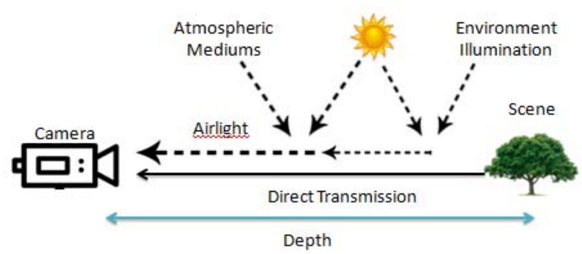

Fig 1. Atmospheric scattering model

B. Comparison Of Different Non-linear Filters

Linear filters are used to reduce the noise but it causes blurring at the edges, but Non-Linear filters are very useful for preserving edges and it also removes multiplicative noise in the image[5]. There are different types ofNon-Linear filters:

1) Homomorphic Filters

Homomorphic filter is a general non-linear technique used in image enhancement and simultaneously it normalizes the brightness and increases the contrast of the image.[6].

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2) Morphological Filters

It is another non-linear operation where the geometric feature is used for edge detection and shape recognition in the image. The two types of operators are erosion and dilation, in erosion filter it decrease the size of the bright image features by interaction with dark areas. In dilation the operation is totally inverse[7].

3) Order Statistic Filter

Order statistic filter response is based on the rank of the pixels, which is enclosed in the image and it replace the value with the center pixel value. There are different types of Order statistic filters are used for various applications which removes the impulsive noise without demolishing the edge details [8].

III. VOLTERRA FILTER

In most of the applications, the approach of linear filter method do not provide acceptable results, so non-linear filter plays an important role for removing haze in the image. The different types of nonlinear systems have been introduced to solve the definite problems. The Volterra filter is one of the | most widely used Non-Linear filter which is also known as polynomial filter[9]. The Volterra filter depends on the coefficients of the filter itself and its execution is described in the frequency domain.

IV. VOLTERRA SERIES MODEL

The filters used in this model are discrete non-linear time invariant systems with memory which is characterized by the discrete Volterra expansion shown in(1) as given by[10]

$$g(n) = y_0 + \sum_{p=1}^{\infty} y_p[h(n)] \quad (1)$$

where

$$y_p[h(n)] = \sum_{m_1=0}^{N-1} \dots \dots \sum_{p=1}^{\infty} y_p(d_1, d_2, \dots . d_p) \times h(n - d_1)h(n - d_2) \dots \dots . . h(n - d_p) \quad (2)$$

where N represents model non-linearity degree $y_p(d_1, d_2, \dots . d_p)$ can be measured as a isolated p^{th} order impulsive response which describe the nonlinear performance of the filter.

V. SECOND ORDER VOLTERRA FILTER

The second order Volterra system has the form shown in (3) as given by[10]

$$g(n)=y_0+\sum_{m1=0}^{\infty} y_1(m_1) f(n-m_1) + \sum_{m1=0}^{\infty} \sum_{m2=0}^{\infty} y_2(m_2, m_1) f(n-m_1) f(n-m_2) \quad (3)$$

where the first term in above equation is linear and second term is non-linear respectively.

y_0 is the offset term $y_1(m_1)$ and $y_2(m_2,m_1)$ are filter coefficients. The Volterra filter resolves the problem by edge enhancement which is proportional to the local image brightness[11].The Volterra coefficients $y_1(m_1)$and $y_2(m_2,m_1)$ are unusual and absolute sum of the sequences.

VI. PROPOSED METHOD

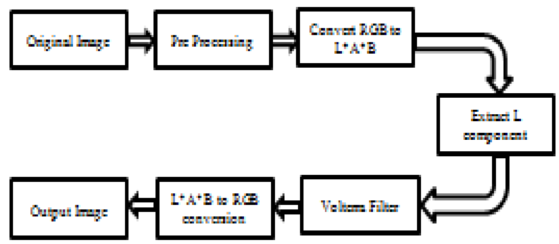


Fig2. Flowchart of proposed algorithm

Step1: Input Original Image : Initially we need to process the original image because of the problem of light scattering. This will lead to poor visibility of the images.
[a b c]=size F(x,y)
Where, a=Number of rows
b=Number of columns
c= size of the original image

Step2: Now RGB image is converted into LAB color space image with the color intensity values of the input image to the LAB color space by using color transformation structure. That is why RGB image do not produce better result.

Step3: After that, L component in the image is extracted which replace the luminous part with the processed data and again convert it back to the RGB image.

Step4: Now we have to apply the image to the Volterra filter to sharpen the edges. The initial output of the Volterra filter is equal to the product of high pass filter and local mean.

Step5: Again we have to convert L*A*B to RGB to get back good result. After that this result is scaled and added to the original image value to produce final output.

VII. Experimental Results

Fig.3.(a),(c),(e),(g) and (i) Original hazy images,(b),(d),(f),(h) and (j) De-hazed images

VIII. Quality Assessment

During image acquisition, storage, processing, transmission and reproduction a number of distortions takes place

There are two methods of image quality evaluation (a) Objective method (b) Subjective method. In Objective method mathematical models are made between the distorted and the haze image to predict the quality of image whereas in subjective method according to human perception the quality of image is predicted[12].

A. Structural Similarity Index Metrics

The Structural similarity(SSIM) index is used to find the quality of the image which is based on the three important terms, ie. luminance, contrast, and structural term. The main aim of the SSIM measures the comparison of the two images as a quality measure of one image is compared, provided other image as a perfect quality. The overall structural similarity index is a product of the three terms which is shown in (4) as given by[13]. Luminance *l(x,y),* contrast *c(x,y)* and structural *s(x,y)* component original image *x* and de-hazed image *y* is shown in below equation(5)(6)&(7)as given by[16].

$$SSIM = [l(x,y)]^{\alpha}.[c(x,y)]^{\beta}.[s(x,y)]^{\gamma} \quad (4)$$

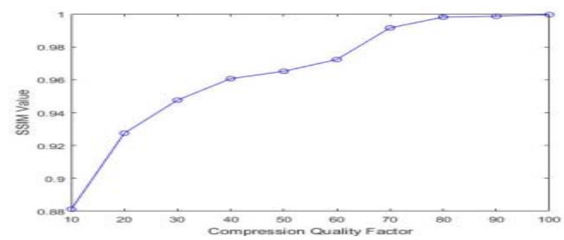
where

$$l(x,y) = \frac{2\mu_x\mu_y + C1}{\mu^2{}_x + \mu^2{}_y + C1} \quad (5)$$

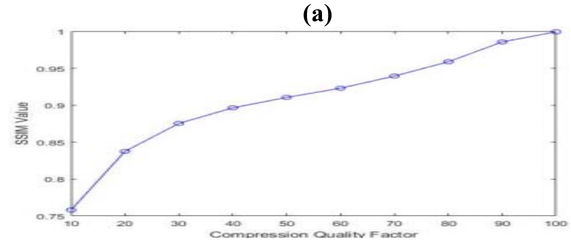
$$c(x,y) = \frac{2\sigma_x\sigma_y + C2}{\sigma^2{}_x + \sigma^2{}_y + C2} \quad (6)$$

$$s(x,y) = \frac{2\sigma_{xy} + C3}{\sigma_x\sigma_y + C3} \quad (7)$$

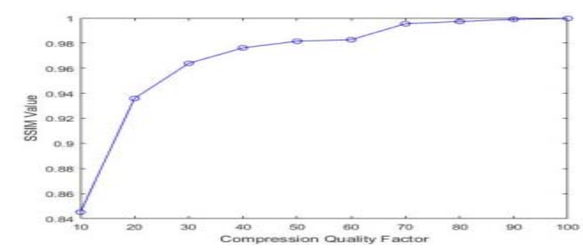
where μ_x & μ_y is the mean, σ_x & σ_y is the variance, $\sigma_x\sigma_y$ is the covariance of original and de-hazed image *x* and *y*.



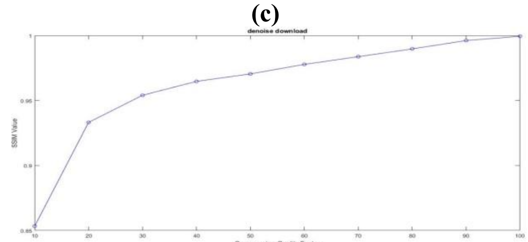
(a)



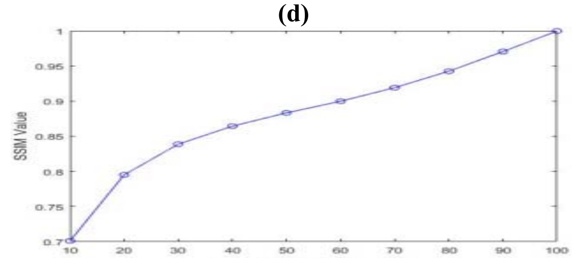
(b)



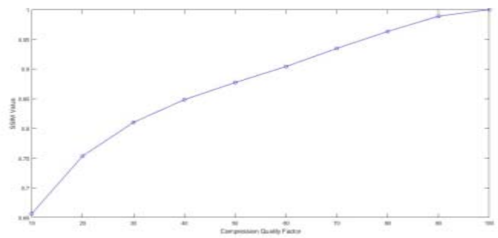
(c)



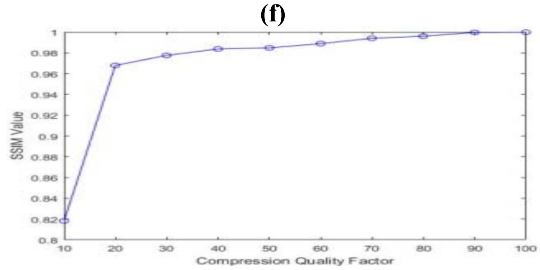
(d)



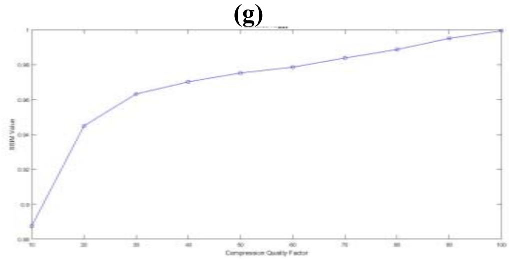
(e)



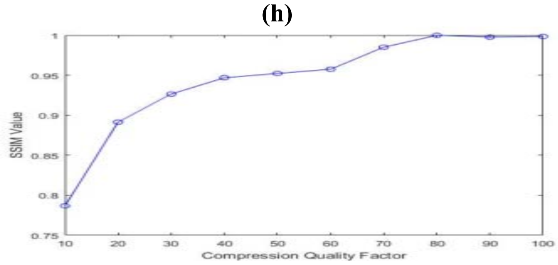
(f)



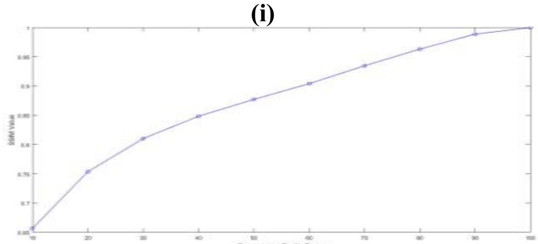
(g)



(h)



(i)



(j)

Fig 4. (a), (c), (e), (g), (i) & (b), (d), (f), (h), (j) SSIM Vs Compression quality factor of Original and De-hazed Image

SSIM metric combines luminance, contrast, and structure into a single quality score. Structures are patterns of pixel intensities among neighbor pixels, after normalizing for luminance and contrast. The Human visual perception system is good for perceiving structure component. Values of SSIM for different images are shown in Fig.4. This shows as the quality factor of the image increases, the SSIM of original and de-haze image increases[14].

B. Peak Signal to Noise Ratio

PSNR is the another quality metrics which helps to identify the degradation in the original image which contained noise with respect to the de-hazed image. PSNR value is expressed in (8) as given by [15]

$$\mathrm{PSNR} = 10\log_{10}\left[\frac{255^2}{2\sigma_{xy}}\right] + 10\log_{10}\left[\frac{SSIM}{1-SSIM}\right] \quad (8)$$

where σ_{xy} is the covariance of original and de-haze image

Table No.1. Comparison of PSNR and SSIM Image Quality measurement at RGB Planes

Images	PSNR			SSIM		
	R	G	B	R	G	B
Image 1	219.88	220.92	221.61	0.70	0.70	0.70
Image 2	222.06	223.25	222.36	0.75	0.75	0.75
Image 3	231.41	232.64	234.96	0.80	0.80	0.80
Image 4	218.67	219.57	224.24	0.85	0.85	0.85
Image 5	224.22	226.95	229.33	1	1	1

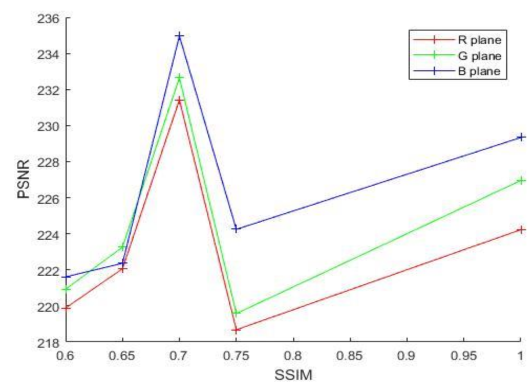


Fig5. PSNR Vs SSIM of different images in RGB plane

As the value of the PSNR value increases, resultant image appears to be smooth by human perception. If the value of the structural similarity index increases the image is approaches to the original image. Highly distorted image shows less value of PSNR and SSIM has the worst value as PSNR is directly proportional to SSIM. If the peak signal value is ∞, then the resultant structural similarity index becomes high. In Fig.5.shows that structural similarity index lies between 0 and 1 which represent the perfect value of the de-hazed image in different RGB planes.

In the previous paper, a wavelet filter is used to remove the haziness in the image, it is suitable for the time-frequency analysis and also helps to find the discontinuous and irregularities in the non-stationary signal but it takes more energy to select the best wavelets for a specific application and implement it correctly. It is shown that in the Volterra model it consequently reduce the non-linear distortion in the signal. Noise has been drastically reduced and image details are sufficiently conserved in this method.

IX. CONCLUSION

In this research paper, we introduce a Volterra based filter for de-hazing of foggy images in bad weather conditions. This method is executed to express the designed algorithm to obtain finest haze-free image with different details.

Volterra filter has the capability to smooth the image by conserving the edge details. After that we have shown the quality metrics of the image as the peak to signal noise ratio value is high, the resultant structural similarity index increases which shows the good quality of image as given by Fig.5.

The performance of our method is evaluated using different parameters for different hazy images as given by Fig.3and obtained a satisfactory result. These results represent the proposed approach is more vigorous and truthful.

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