

PERFORMANCE ANALYSIS OF HAZE REMOVAL TECHNIQUE USING ADVANCED DARK CHANNEL PRIOR FILTER

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Abstract: Images of outdoor scenes are usually degraded by the turbid medium (e.g., particles, water-droplets) in the atmosphere. Haze, fog, and smoke are such phenomena due to atmospheric absorption and scattering. The irradiance received by the camera from the scene point is attenuated along the line of sight. Furthermore, the incoming light is blended with the airlight. The degraded images lose the contrast and color fidelity. In poor weather condition, fog removal from an image is an unavoidable problem. Various methods of fog removal have been described in literature. Initially, methods using multiple images which included the use of polarization filter. This method suffers from high time complexity and requirement of multiple images, resulting in non suitability to real time applications. This lead to the development of single image fog removal technique such as Dark Channel Prior (DCP), Improved Dark Channel Prior (IDCP), Dark channel prior with Histogram Specification, Anisotropic Diffusion and Improved Dark Channel Prior using Guided Filter. The former strategy is used for estimating and refining transmission map while the later is used to estimate and refine air-light. Existing methods for Haze removal are inefficient for computation of air-light. There is a need of an efficient method for calculation of air-light and one method for final noise filtration with edge sharpness enhancement. This dissertation provides a hybrid strategy based on IDCP using Guided Filter. In most of the previous existing single image methods, the atmospheric light is estimated from the most haze-opaque pixel. For example, the pixel with highest intensity is used as the atmospheric light. But in real images, the brightest pixel could on a white car or a white building. The dark channel of a haze image approximates the haze denseness well. In proposed method, the dark channel is used to improve the atmospheric light estimation because the intensity of the dark channel is a rough approximation of the thickness of the haze. This property is used to estimate the transmission and the atmospheric light. We first pick the top 0.1% brightest pixels in the dark channel. These pixels are most haze opaque. Among these pixels, the pixels with highest intensity in the input image are selected as the atmospheric light. This simple method based on the dark channel prior is more robust than the existing “brightest pixel” method. Also, the guided filter performs very well in terms of both quality and efficiency in a great variety of applications, such as noise reduction, detail smoothing/enhancement and blur removal on image before final recovery of haze free image. In addition, this research work will compare the above mentioned techniques using several performance metrics such as Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), Haze Improve Index and Visibility Metric. MATLAB R2013a has been used as an implementation platform. Image processing toolbox and generalized toolbox are used from MATLAB software. The results will reflect the visual quality of our hybrid approach is much better as well as the performance metrics mentioned above images to a great.

Index terms- Image, dehaze, Haze, Air-light, Contrast, Attenuation, Dark channel

I. INTRODUCTION

Images of outdoor scenes are usually degraded by the turbid medium (e.g., particles, water-droplets) in the atmosphere. Haze, fog, and smoke are such phenomena due to atmospheric absorption and scattering. The irradiance received by the camera from the scene point is attenuated along the line of sight. Furthermore, the incoming light is blended with the airlight (ambient light

reflected into the line of sight by atmospheric particles). The degraded images lose the contrast and color fidelity, as shown in Figure 1(a). Since the amount of scattering depends on the distances of the scene points from the camera, the degradation is spatial-variant.



Fig.1 Haze removal using a single image. (a) Input haze image (b) Image after haze removal by our approach

Haze removal (or dehazing) is highly desired in both consumer/computational photography and computer vision applications. First, removing haze can significantly increase the visibility of the scene and correct the color shift caused by the air light. In general, the haze-free image is more visually pleasing. Second, most computer vision algorithms, from low-level image analysis to high-level object recognition, usually assume that the input image (after radiometric calibration) is the scene radiance. The performance of vision algorithms (e.g., feature detection, filtering, and photometric analysis) will inevitably suffer from the biased, low-contrast scene radiance. Last, the haze removal can produce depth information and benefit many vision algorithms and advanced image editing. Haze or fog can be a useful depth clue for scene understanding. The bad haze image can be put to good use.

In this, author proposes a novel prior - dark channel prior, for single image haze removal. The dark channel prior is based on the statistics of haze-free outdoor images. Author finds that, in most of the local regions which do not cover the sky, it is very often that some pixels (called "dark pixels") have very low intensity in at least one color (rgb) channel. In the haze image, the intensity of these dark pixels in that channel is mainly contributed by the air light. Therefore, these dark pixels can directly provide accurate estimation of the haze's transmission. Combining a haze imaging model and a soft matting interpolation method, author can recover a hi-quality haze-free image and produce a good depth map (up to a scale) [1].

The haze removal techniques can be classified into two categories: image enhancement and image restoration. Image enhancement doesn't include the reason why fog degrades image quality. This technique enhances the contrast of haze image but it leads to loss of information in image. Image restoration studies the physical procedure of imaging in fog.

After observing degradation style of fog, image will undoubtedly be established. At last, the degradation process is used to produce the fog free image.

II. FOG REMOVAL TECHNIQUES

As a way to remove the fog effect from the image various fog removal methods are used. By eliminating fog, visibility of the image can be increased and the color shift due to the air light can even be verified to a large extent. In this section, various defogging techniques are discussed which are classified on the basis of number of images used (see Fig. 2.3).

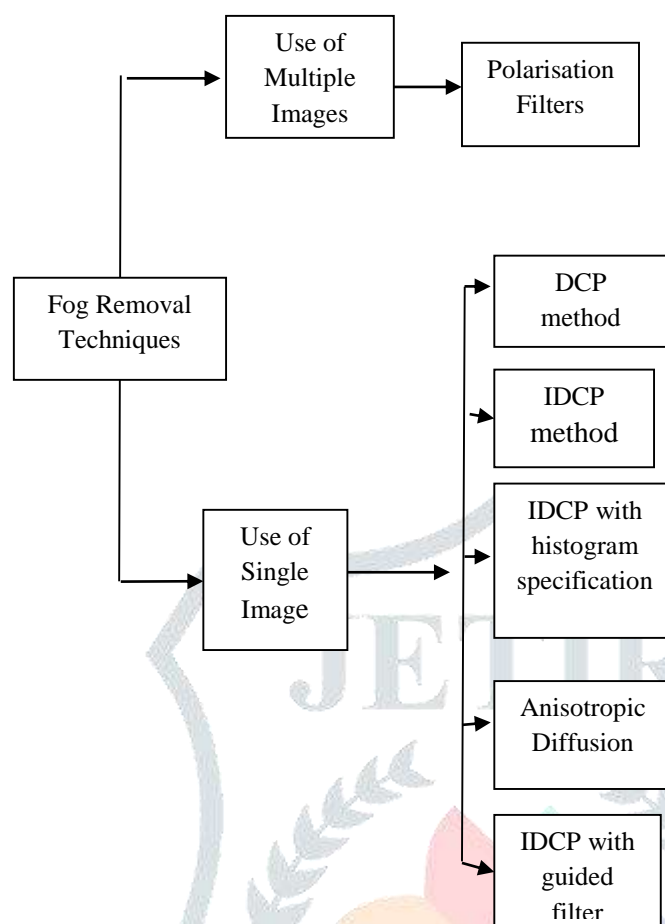


Fig. 2.3 Various Fog Removal Techniques

2.1 Use of multiple images

2.1.2 Polarisation FILTER:

Fog from the image can be removed by multiple image method using Polarization filter [10-11]. While capturing an image from a distance z , the reflected light from the object to the camera is called direct light, D . The portion of light scattered due to environmental illumination in the same direction of direct light arriving in the camera is termed as air-light, A .

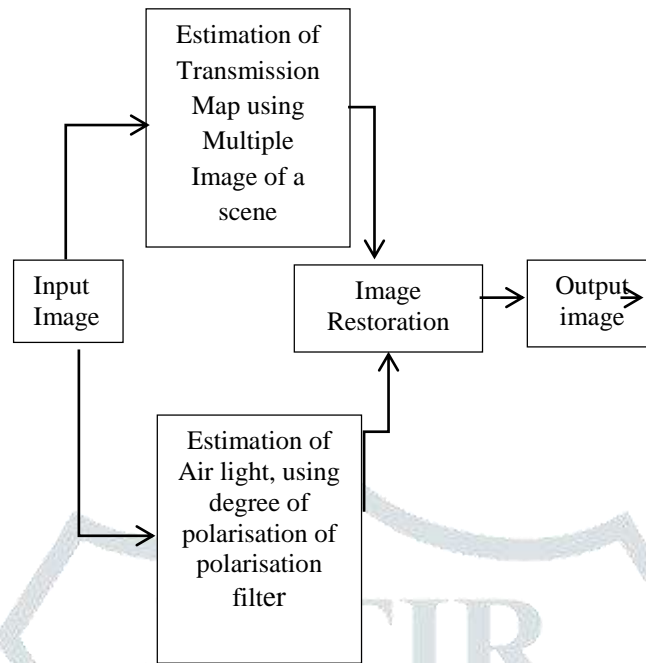


Fig. 2.4 Block diagram of defogging by Polarization filter

Assuming that the direct light may be denoted as follows:

$$D = J(x).t(x) \quad (2.6)$$

Where x is the real world ray corresponding to the pixel and $J(x)$ is the surface radiance vector and

$$t = \exp\left[-\int_0^z \beta(z', \lambda) dz'\right] \quad (2.7)$$

is the transmittance of the atmosphere. It depends on the distance z between the object and the camera and on the atmospheric coefficient β . When atmospheric attenuation coefficient is independent to the position, $\beta(z', \lambda)$ is the constant. t becomes

$$t = \exp\left[-\int_0^z \beta dz'\right] = \exp\left[-\beta \int_0^z dz'\right] = \exp[-\beta z] \quad (2.8)$$

The air-light may be described as the light coming from the source towards the observer. When we use polarization filters, we consider that the air-light is partially polarized. Hence, the polarizer may be modulated to estimate the air-light components. When the polarizer is rotated, we obtain two states where the intensity will be either minimum or maximum. This intensity changes due to the reason that another direction of air-light is filtrated. The orientation where the air-light contribution is most intense, it is denoted by $A(x)^{\max}$ and where the air-light contribution is least, it is denoted by $A(x)^{\min}$.

Hence, the air-light (A_{light}) may be expressed by:

$$A_{\text{light}} = A(x)^{\max} + A(x)^{\min} \quad (2.9)$$

Here, the assumption is that the direct transmission is not polarized; its energy is evenly distributed between the polarization components. Hence, the intensity of scene can be expressed as:

$$I(x)^{min}=D(x)/2+A(x)^{min} \quad (2.10)$$

$$I(x)^{max}=D(x)/2+A(x)^{max} \quad (2.11)$$

Where $D(x)$ is the direct attenuation

We use the definition of visibility to define the degree of polarization p , which defines the air-light degree of polarization as:

$$p(x)=(A(x)^{max}-A(x)^{min})/A_{light} \quad (2.12)$$

Supposition is that p is a constant, ranging from 0 to 1.

So,

$$A(x)^{max}=A_{light}(1+p)/2 \quad (2.13)$$

$$A(x)^{min}=A_{light}(1-p)/2 \quad (2.14)$$

Hence, the total intensity can be expressed as:

$$I(x)^{total}=I(x)^{max}+I(x)^{min} \quad (2.15)$$

2.1.2 Image Recovery

For recovering an image ($J(x)$), the airlight must be estimated as

$$A'_{light}=(I(x)^{max}-I(x)^{min})/p \quad (2.16)$$

Finally, the image is recovered using the airlight and transmittance

$$J'(x)=(I(x)^{total}-A'_{light})/t'(x) \quad (2.17)$$

2.1.3 Advantages

- It correctly estimates the air-light.

2.1.4 Disadvantages

- Time Complexity is very high.
- It requires multiple images for fog removal.

2.2 Use of single image

2.2.1 Dark Channel Prior (DCP) Fog from an image is removed by using a single image fog removal method. The most predominant method is DCP [13-14] method. It estimates both transmission map as well as air-light to recuperate the original image from foggy image.

2.2.1.1 Dark Channel Creation

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

$$J_{dark}(x) = \min_{c \in \{r, g, b\}} \left(\min_{y \in p(x)} (J_c(y)) \right) \quad (2.18)$$

Where J^c is a colour 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 as shown in Fig. 2.

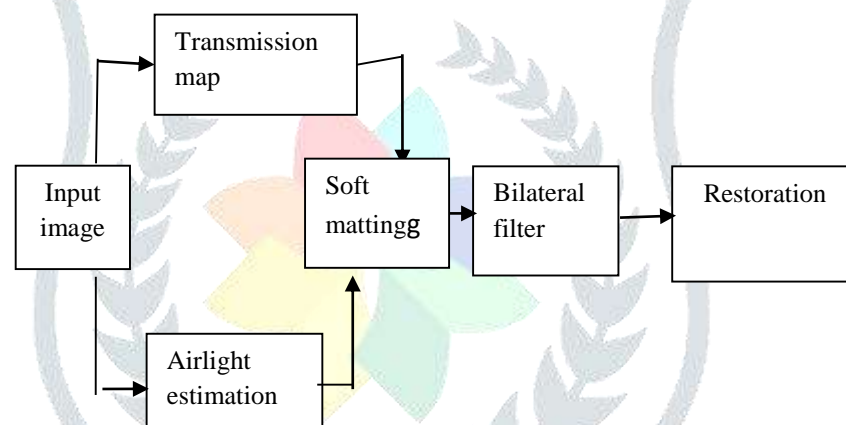


Fig. 2 Block diagram of DCP

Detail explanation of each block is as follows:

Transmission Map Estimation

Firstly, haze image equation which is given by equation (2.5) is normalized by A as:

$$\frac{I^c(x)}{A^c} = \frac{t(x)J^c(x)}{A^c} + (1 - t(x)) \quad (2.19)$$

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. We observed that the dark channel of an image is close to zero. Since, A is some positive quantity.

$$J^{dark}(x) = \min_{c \in \{r, g, b\}} \left(\min_{y \in p(x)} (J^c(y)) \right) = 0 \quad (2.20)$$

As $t(x)$ is constant in a patch. Therefore, we rewrite the equation (2.19) for estimation of transmission map as:

$$\hat{t}(x) = 1 - \min_{y \in p(x)} \left(\min_c \left(\frac{I^c(x)}{A^c} \right) \right) \quad (2.21)$$

We keep some amount of haze in an image by adding a factor called w ($0 < w \leq 1$) so that image looks natural. Hence, the new estimated transmission map is given by equation (2.22):

$$\check{t}(x) = 1 - w * \min_{y \in p(x)} \left(\min_c \left(\frac{I^c(x)}{A^c} \right) \right) \quad (2.22)$$

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

Soft matting

The haze image equation which given by equation (2.5) is similar to image matting [15] equation (2.23):

$$I(x) = F\alpha + B(1 - \alpha) \quad (2.23)$$

Where F and B are foreground and background colours respectively and α is foreground opacity which is exactly similar to transmission map in haze image equation.

Now, refined transmission map is denoted by $\check{t}(x)$ and Rewriting $t(x)$ and $\check{t}(x)$ in their vector forms as t and \check{t} , to minimize the following cost function given by equation (2.24)

$$E(y) = t^T L t + \lambda (t - \check{t})^T (t - \check{t}) \quad (2.24)$$

Here, first term represents the smoothness and second represents the data term having weight λ . L denotes the laplacian matrix whose elements are defined by equation (2.25):

$$\sum_{k|(i,j) \in w_k} \left(\delta_{ij} - \frac{1}{|w_k|} \left(1 + (I_i - \mu_k)^T \left(\Sigma_k + \frac{\epsilon}{|w_k|} U_3 \right)^{-1} (I_j - \mu_k) \right) \right) \quad (2.25)$$

Here, I_i and I_j are the colours 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 colours in window w_k , U_3 is a 3×3 identity matrix, ϵ 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 (2.26):

$$(L + \lambda U)t = \lambda \check{t} \quad (2.26)$$

Bilateral filter

The purpose of applying bilateral filter [16-19] is to preserve the edges of an image.

Air-light estimation

We pick the top 0.1 % brightest pixel of dark channel prior and among these pixels, the pixel with highest intensity in input haze image I is considered as air-light.

Restoration

Finally, Image is recuperated using the equation (2.27) given by:

$$J(x) = \frac{(I(x)-A)}{(\max(t(x), t_0))} + A \quad (2.27)$$

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 air-light.
- It may be invalid when scene object is intrinsically similar to air-light (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.

2.2.2 Improved Dark Channel Prior (IDCP)

Yan Wang and Bo Wu proposed a algorithm called Improved Dark Channel prior [20], 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.

2.2.2.1 Dark Channel Creation

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

$$J_{dark}(x) = \min_{c \in \{r, g, b\}} \left(\min_{y \in p(x)} (J_c(y)) \right) \quad (2.28)$$

Where J^c is a colour 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 IDCP is as shown in Fig. 3

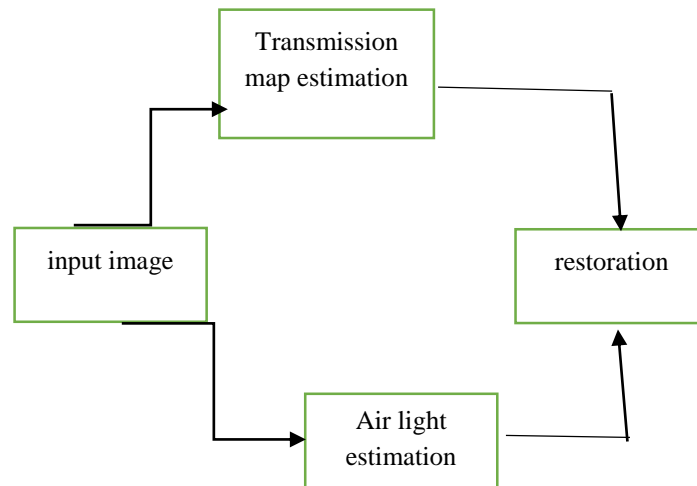


Fig. 3 Block diagram of IDCP

The detailed explanation of each block is as given below:

Transmission Map Estimation

Firstly, haze image equation which is given by equation (2.5) is normalized by A as:

$$\frac{I^c(x)}{A^c} = \frac{t(x)J^c(x)}{A^c} + (1 - t(x)) \quad (2.29)$$

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. We observed that the dark channel of an image is close to zero. Since, A is some positive quantity.

$$J^{\text{dark}}(x) = \min_{c \in \{r, g, b\}} \left(\min_{y \in p(x)} (J^c(y)) \right) = 0 \quad (2.30)$$

As $t(x)$ is constant in a patch. Therefore, we rewrite the equation (2.29) for estimation of transmission map as:

$$\hat{t}(x) = 1 - \min_{y \in p(x)} \left(\min_c \left(\frac{I^c(x)}{A^c} \right) \right) \quad (2.31)$$

We keep some amount of haze in an image by adding a factor called w ($0 < w \leq 1$) so that image looks natural. Hence, the new estimated transmission map is given by equation (2.32)

$$\hat{t}(x) = 1 - w * \min_{y \in p(x)} \left(\min_c \left(\frac{I^c(x)}{A^c} \right) \right) \quad (2.32)$$

IDCP doesn't employ any soft matting technique for refinement of transmission map since it is very time consuming step.

Air-light 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 stated below:

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

Image restoration

Finally, Image is recuperated using the equation (2.33) given by:

$$J(x) = \frac{(I(x)-A)}{(\max(t(x), t_0))} + A \quad (2.33)$$

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.

III.PROPOSED METHODOLOGY

Fig. 4. shows the block diagram of the proposal which states that the best results are obtained if we first estimate the air-light using anisotropic diffusion method while transmission map is estimated using DCP algorithm and refined using Guided Filter, then the restored image will not only have better picture quality but will also achieve higher PSNR.

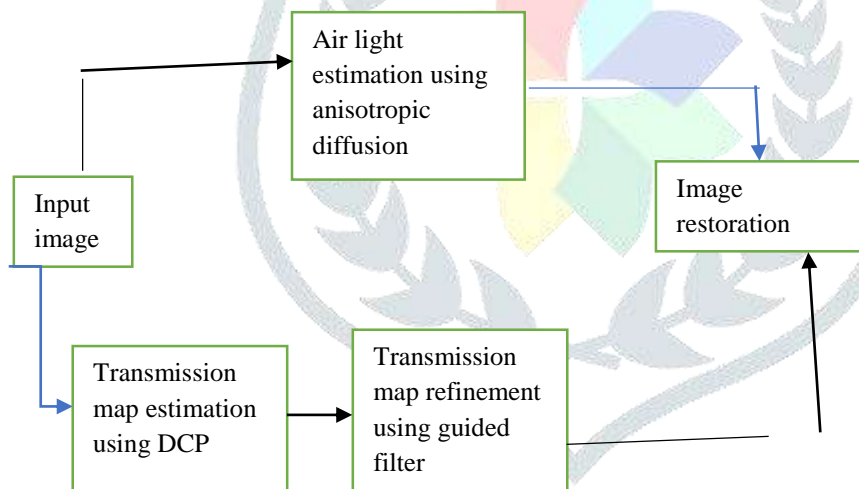


Fig.4 Block diagram of Proposal

Here's the some steps of implementation

1. Inputting of Hazed Image
2. Calculation of Dark Channel Prior from Hazed image

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

Where J^c is a color channel of J and $p(x)$ is a local patch centred at x

J^{dark} Dark channel of J and its low and tends to be zero

J is Haze free outdoor image

3. Computation of Atmospheric light
4. Estimation of transmission

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

Where $I^c(x)$ is the intensity of foggy image I of x^{th} pixel

$t(x)$ is transmission map

A is global atmospheric light

5. Application of Guided filter
6. Computation of final recovered image by calculating final scene Radiance (J)

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

IV. RESULTS

MATLAB R2013a has been used as an implementation platform. Image processing toolbox and generalized toolbox are used from MATLAB software. The results reflected in the visual quality of our hybrid approach is much better as well as the performance metrics mentioned above images to a great. In proposed method, the dark channel is used to improve the atmospheric light estimation because the intensity of the dark channel is a rough approximation of the thickness of the haze. This property is used to estimate the transmission and the atmospheric light. We first pick the top 0.1% brightest pixels in the dark channel. These pixels are most haze opaque. Among these pixels, the pixels with highest intensity in the input image are selected as the atmospheric light. This simple method based on the dark channel prior is more robust than the existing “brightest pixel” method. Also, the guided filter performs very well in terms of both quality and efficiency in a great variety of applications, such as noise reduction, detail smoothing/enhancement and blur removal on image before final recovery of haze free image. In addition, we have compared the above mentioned techniques using several performance metrics such as Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), Haze Improve Index and Visibility Metric. For doing the experiment we have taken three images named as ‘park.png’, ‘forest.bmp’ and ‘tian.bmp’. The proposed method is applied on all three images and output meters are evaluated and compared as shown in table 1 and table 2. We have also taken the snapshot of various output stages of hazy image when inputted to proposed method through MATLAB. Figure 5 is the snapshot of original hazy image. Figure 6 is the snapshot of dark channel prior of hazy image. Figure 7 is the snapshot of guided filtered transmission map of hazy image. Figure 8 is the snapshot of recovered non-hazy image. Figure 9 is the snapshot of comparison of hazy and non-hazy image with visibility matrix index.



Fig.5 snapshot of original hazy image



Fig.6 snapshot of dark channel prior of hazy image



Fig.7 snapshot of guided filtered transmission map of hazy image

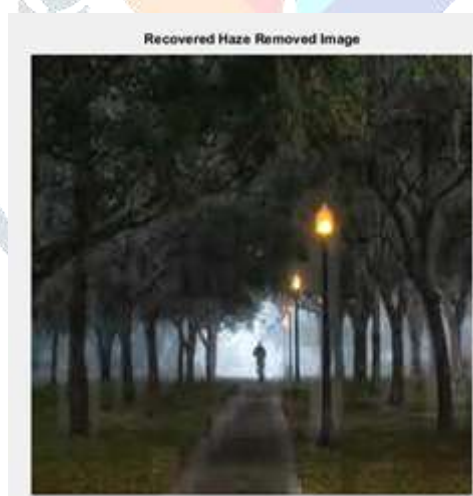


Fig. 8 snapshot of recovered non-hazy image



Fig.9 snapshot of comparison of hazy and non-hazy image with visibility matrix index (park.png)









Fig.10 snapshot of comparison of hazy and non-hazy image with visibility matrix index (forest.bmp)

Table 1 Comparative analysis of PSNR, MSE and Haze Improve Index value for between hazy and non-hazy image

s.no.	Image	PSNR	RMSE	Haze Improve
1	Park.png	64.192	0.0248	4.8662
2	forest.bmp	80.014	6.48e-04	6.9276
3	tian.bmp	71.739	0.0044	1.8278

Table 2 Comparative analysis of visibility matrix value for different hazy and non-hazy image

S.No.	Image	Hazy Image with Visibility Matrix	Non-Hazy Image Visibility Matrix

1.	Park.png		
		VM = 119.3	VM = 124.2
2.	forest.bmp		
		VM = 226.4	VM = 233.3
3.	tian.bmp		
		VM = 128.7	VM = 156.7

V. CONCLLUSION

The dark channel is used to improve the atmospheric light estimation because the intensity of the dark channel is a rough approximation of the thickness of the haze. The results reflected in the visual quality of our hybrid approach is much better as well as the performance metrics mentioned above images to a great. DCP is more robust than the existing “brightest pixel” method. The guided filter performs very well in terms of both quality and efficiency in a great variety of applications, such as noise reduction, detail smoothing/enhancement and blur removal on image before final recovery of haze free image. We also compared the above

mentioned techniques using several performance metrics such as Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), Haze Improve Index and Visibility Metric.

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