Hazy Image Enhancement Using Cross Bilateral Filter

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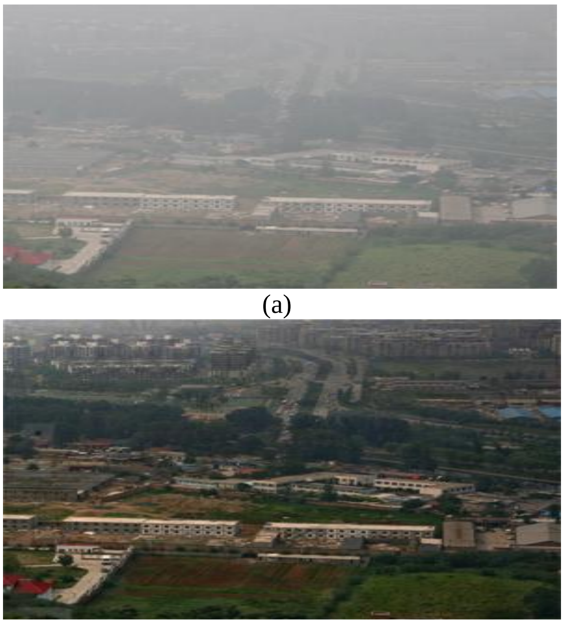
ABSTRACT
Haze is an atmospheric property where mist, dust, fog and smoke plays a major role in concealing the contrast of the images. Hazy images thus formed cannot provide a clear understanding of the image that has to be used for many applications. Haze removal is a challenging task because the scene radiance must be recovered with a little information available. In this proposal, a new method of color degradation prior is provided by using which the depth of the image is recovered. With the available depth map of the hazy image the scene radiance is restored using the atmospheric scattering model. This method helps in effectively removing the haze from a single image.
Keywords: *Haze Removal, Dehazing, Color Degradation Prior, Fog Removal, Scene Radiance, Depth Restoration.*

I. INTRODUCTION

Haze removal refers to different methods that aims in reducing or removing the degradation or alteration of color and contrast of images taken in bad weather conditions. The degradation of the image is due to various factors like object-camera motion, camera mis focus, bad weather conditions and others. Normally, bad weather such as fog, haze, mist, smoke, etc., in an image plays a major role in disturbing the clear scene. Haze formation is mainly due to the fact that light is absorbed and gets scattered by the turbid particles. Owing to this fact there is a notable delay in the color and contrast of an image.

Removal of haze in an image helps in many computer vision and automatic systems application. Also the images must have a clear visibility of the scenes for applications such as surveillance, vehicles monitoring, object recognition, aerial imagery, video analysis/retrieval, remote sensing, object classification, etc., Haze removal becomes a very difficult task due to the fact that the concentration of haze is not equal in all places, they differ from place to place. Recovering the scene radiance of a hazy image requires depth information. This recovery of the depth map is a very challenging area where the depth must be restored with a little amount of information available. Many research have been carried out for removing haze and two major methods namely Multiple image haze removal and single image haze removal has been proposed so far and they are widely used. Image enhancement is the process that enhances the contrast of fog picture. Image restoration understands the physical process of imaging under foggy weather. Several algorithms have been proposed to enhance the quality of images taken under bad weather conditions, focusing for instance on visibility.



(a)

(b)

Figure 1: (a) A hazy image. (b) Haze free image

Earlier research on dehazing made use of some traditional methods like histogram based [2]-[7] methods to remove haze from image. Later the area of dehazing was further supported by multiple images dehazing method in which multiple images of the same scene are taken. These methods were used because multiple images can provide a lot of information than a single image. The polarisation [1] method was one in which multiple images that are taken under different weather conditions are used for dehazing. The other method that used the multiple images was proposed by Narasimhan et al

[3] in which multiple images of the same scene are taken under different weather conditions.

Many significant works has emerged recently that uses a single image for dehazing. According to Tan [4] method the local contrast of the image is maximized based on the markov random field to get a haze free image. But since the contrast is maximized, sometimes it may lead to over saturated images. Schaul and et al [6] concentrated on the outdoor photography that the distance objects appear blurred and loses its color due to the degradation level of the atmospheric haze. The key idea used here is the fusion of visible and near infrared of the given input image to obtain a haze free image. Rannan Fattal provide that [5] the shading and transmission of signals are un-correlated, by using this the airlight-albedo ambiguity can be resolved. Independent Component Analysis (ICA) is used here to estimate the transmission, and the color of the image is deducted by Markov Random Field (MRF). This approach is time consuming and cannot be used in gray scale images. Dark Channel prior technique [8]-[9] is the most popular technique of the above mentioned methods. It is based on the fact that most local patches in a not sky region has some pixels at very low intensity in atleast one color channel. From this low intensity pixel the thickness of the haze can be easily accessed and can restore a clear haze free image. This low intensity pixels are mainly due to three reasons namely colorful objects or surfaces (green grass, tree, blossom), shadows, dim objects or surfaces (dark tree trunk, stone). By using the low intensity pixels the transmission map can be estimated and combined with the haze imaging model and then soft matting technique is applied to recover a high quality haze free image. This method consists of different phases such as, image segmentation, estimation of atmospheric light and cost function. This method is very effective that several variations of this method are proposed so far. The time consuming soft matting is replaced by Yu et al [10], He et al [11] and Tarel et al [12] with standard median filtering, joint bilateral filtering and guided image filtering in the dark channel prior technique. Anisotropic diffusion method [13] is independent of the density of fog and does not require user intervention. This algorithm works for HSI (hue, saturation and intensity) model and the computation is decreased. Tang et al [14] combined four types of haze relevant features to estimate transmission.

II. SYSTEM ARCHITECTURE

In this paper an effective color degradation prior approach is proposed that effectively removes the haze from a single image. The atmospheric scattering model is studied at first which includes the study of the formation of haze into consideration. The color degradation technique is applied to identify the hazy regions approximately by the fact that the saturation in a haze free region will be more than the hazy region. By using this, linear model is constructed with a learning method and the transmission is estimated. The depth of the image can be restored by applying bilateral filtering to the edge preserved image. Then with the depth information is recovered, the scene radiance is restored and a haze free image is obtained. The architecture diagram is given as follows.

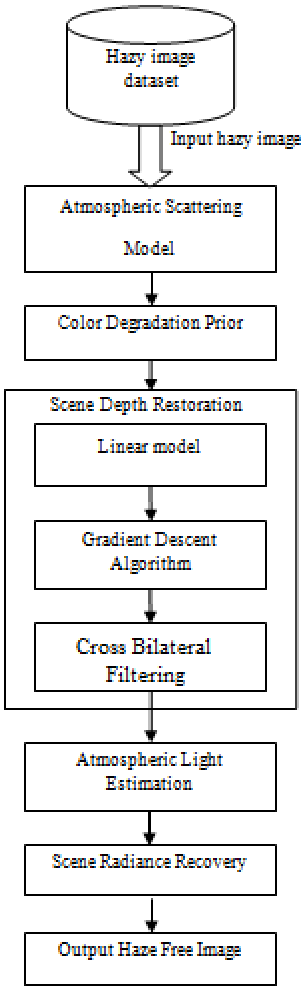


Figure 2: Proposed System Architecture

The atmospheric scattering module which is widely used for dehazing image and gives a concise analysis on the parameters of this model is discussed in the next section followed by the color degradation technique.

III. ATMOSPHERIC SCATTERING MODEL

A. *Formation of Hazy Image*

The formation of the hazy image is mainly influenced by the fact that the light from the camera source is absorbed and scattered by the turbid medium such as water droplets in the atmosphere.

Scattering is caused by two fundamental phenomenon namely attenuation and air-light. Haze is thus referred as the addition of air-light and attenuation to an image, denoted as:

$$\text{Haze} = \text{Attenuation} + \text{Air-light} \quad (1)$$

Narasimhan and Nayar further derived the model and the equation can be expressed as

$$I(x) = j(x).t(x) + A(1-t(x)) \quad (2)$$

Where x denotes the position of the pixel, I indicates the observed hazy image, The scene radiance j depicts the haze free image that is to be restored, A is the global atmospheric air light, t is the medium of transmission that describes the portion of the light that reaches the camera without getting scattered. I, J and A all are three dimensional vectors in the RGB color space. Since the I value is known the main goal of dehazing is to find A and t and to restore scene radiance j as given in the above equation.

Therefore from the above equation it is clearly understood that, the image captured by the observer is the combination of both the attenuated version of the scene radiance with an additive form of haze layer, where the atmospheric light equals the colour of the haze.

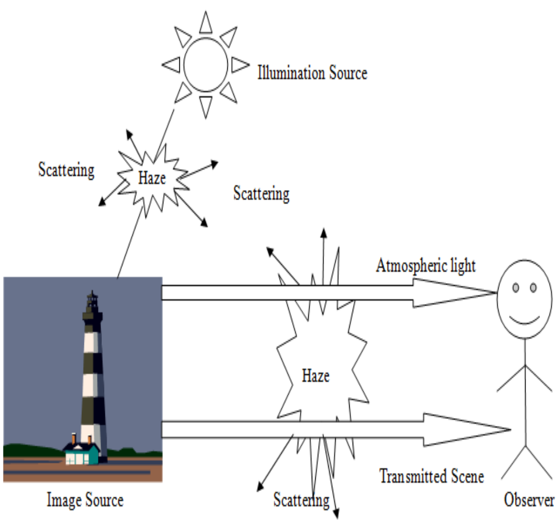


Figure 3: Hazy Image Formation

B. *Attenuation*

Attenuation means the gradual loss in intensity of any kind of flux through a medium.On account of the scattering of atmospheric light, a fraction of light gets affected from the incident ray. The unscattered portion of light is called the medium transmission, which is transmitted to the observer.Mathematically attenuation can be expressed as:

$$\text{Attenuation} = t(x).j(x) \quad (3)$$

Here, J(x) represents the scene radiance and t(x) is the medium transmission. The Attenuation describes the radiance of the scene and its distortion in the medium.

The transmission has a scalar value that has a range from 0 to 1 for each pixel and the value denotes the depth information of the scene objects directly. For a uniform homogenous atmosphere, the transmission t(x) is given as:

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

β represents the scattering coefficient of the atmosphere and d is the scene depth for the pixel x. The scattering coefficient β can be a constant under the homogeneous atmospheric condition. In ideal cases the range of d(x) is normally [0, +∞) since the objects in the image can be far away from the observer. The scene radiance gets attenuated exponentially with the depth. If the transmission is recovered then the depth map can also be recovered.

C. *Air-light*

This airlight shows that how the atmosphere acts as a source to reflect the environmental illumination towards the observer.Air-light is formed mainly due to the scattering of the light. Air-light is normally termed as adding more brightness to the scene. It is an additive property, measured as the distance between camera and object. The mathematical equation of air-light is denoted as:

$$\text{Air-light} = A(1-e^{-\beta d(x)}) \quad (5)$$

The image dehazing comes under constraint problem. Haze removal or image dehazing is one of the highly recommended computer vision applications that normally tries to remove the hazy areas from the captured hazy image which allows to a get a better and natural haze free image. when dehazing for a colour or gray image is performed the transmission coefficient t(or the alpha map) is unknown also the atmospheric light A and the scene radiance J is unknown. Therefore if the airlight and the transmission $t$are found then the scene radiance can be easily recovered.

IV. COLOR DEGRADATION PRIOR

This technique is mainly based on the fact that human brain can easily identify the hazy areas in the image without any additional methods. This paved the way to conduct many experiments for identifying the hazy areas in the image. The outcome of this experiment is found that the brightness and saturation of the image vary highly in heavy concentration of the haze.

In a normal image, the brightness will be moderate and the saturation will be more than the brightness which leads to the difference between them close to zero. But in a hazy image, under the influence of haze the saturation will be decreased and the brightness will be more. This fading leads to a high difference between the brightness and the saturation. This becomes worse in more dense haze regions that the color of the scene is very difficult to be identified and difference will be more in such places.

Figure 3 depicts the dense-haze and the haze free regions in a image. Without the influence of the haze the images have high saturation. This situation is complex in a hazy image. In case of direct attenuation the brightness tends to decrease. But due to the scattering of the light the brightness gets enhanced reducing the saturation leading to a hazy image formation. The white or the gray light of the brightness is additive in nature. The airlight plays a major role in increasing the brightness of the scene. The strong influence of the airlight gives more difference between the brightness and the saturation by which the concentration of the haze can be found.

$$d(x) \alpha c(x) \alpha v(x) - s(x) \quad (5)$$

Here d is the depth of the scene, c is the haze concentration, v is the brightness if the image and s is the saturation of the image. The concentration of the haze is directly propotional to the difference between the brightness and the saturation. And the depth of the scene is prpotional to the concentratio. This methodology is called color degradation prior.

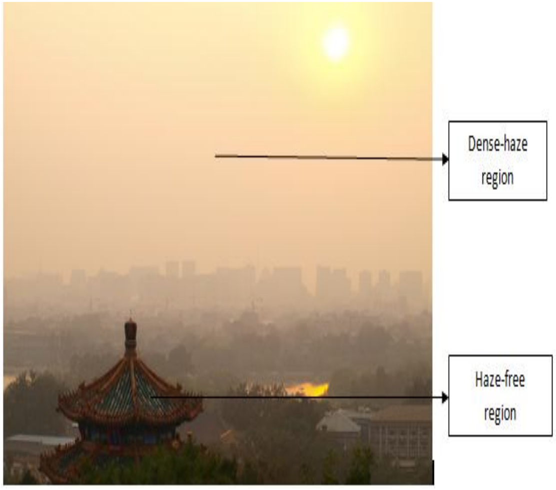


Figure 4: Dense haze and haze free region

The color degradation prior can be identified using the HSV color model. As the depth of the scene increases, the saturation s decreases and brightness v increases. The result of this color degradation prior is not very accurate the accurate expressions are provided in the next modules.

V. SCENE DEPTH RESTORATION

The difference between the saturation and the brightness can only approximately predict the concentration of haze. To be more accurate then the model must be preceded as follows.

D. Linear model

The relationship among the saturation s, brightness v and depth d is assumed to be linear. By using this assumption a linear model is constructed as given below

$$d(x) = \theta_0 + \theta_1 v(x) + \theta_2 s(x) + \varepsilon(x) \quad (6)$$

Here x is the position within the image, d is the scene depth, v is the brightness component of the hazy image, s is the saturation component, θ_0, θ_1, θ_2 are the unknown linear coefficients, $\varepsilon(x)$is a random variable representing the random error of the model, and ε is regarded as a random image. We use a Gaussian density for ε with zero mean and variable σ^2.

The gradient of this model is calculated to find the direction of the haze. Also this model has a edge preserving property. The gradient of the depth can be calculated as given in equation (6)

$$\nabla d = \theta_1 \nabla v + \theta_2 \nabla s + \nabla \varepsilon \quad (7)$$

The value of $\varepsilon(x)$ tends to be very low, close to zero, d has an edge only if I has an edge. The depth information can be well recovered even near depth discontinuities in the scene. Both the random image

ε and the gradient image $\nabla\varepsilon$ are dark. The sobel image is first generated with the θ values initially as
θ_1= 1.0, θ_2= -1.0 and ε is a random image. The edge is preserved in the gradient calculation and a linear model is created to find the accurate value of the coefficients.

E. Gradient Descent Algorithm

The exact value of the linear coefficients θ_0, θ_1, θ_2 is found by gradient descent algorithm. The training model is trained by using several samples and best values are got. Once they are determined, they can be used for any single image. The gradient descent is used to find the local minimum of a function and it starts with a initial guess.

Algorithm 1
Input: training brightness vector *v*, saturation vector *s*, depth vector *d*, no of iterations t.
Output: linear coefficients θ_0 ,θ_1 ,θ_2 , the variable σ^2
Auxiliary functions:
Size of the vector: n = size(in)
Calculating square: out = square(in)

```
Begin
n=size(v);
θ0=0, θ1=1, θ2 =-1;
sum=0; wsum=0;vsum=0;ssum=0;
for iteration from 1 to t do
   for index from 1 to n do
      temp = d[i]- θ0 - θ1 * v[i]- θ2 * s[i];
      wsum = wsum + temp;
      vsum = vsum + v[i]*temp;
      ssum = ssum + s[i]*temp;
      sum = sum + square(temp);
   end for
   σ^2 =sum/n;
   θ0 = θ0 +wsum; θ1 = θ1+vsum; θ2 = θ2+sum;
end for
End
```

C. Cross bilateral filtering

The relationship among the scene depth *d*, the brightness *v* and the saturation *s* has been established and the coefficients have been estimated, the depth map of a hazy image can be restored. But the white objects in an image are usually with high values of the brightness and low values of the saturation. In that case, the proposed model tends to consider the scene objects with white color as being distant which results in inaccurate estimation of the depth in some cases. The cross-bilateral filter is a variant of the typical bilateral filter. The cross-bilateral filter actually computes the range kernel from a cross (guidance) channel. The results obtained by the transmission map using cross bilateral filtering can exhibit sharper edges than those obtained by the Gaussian and bilateral filters. The selection of the range for $\sigma_r$is important for the accuracy of the transmission map, and normally the best value of σ_r was found around 0.1 regardless of the size of the local patch. The visual image obtained after the cross bilateral filter is superior when compared to the images obtained from other method.

VI. ATMOSPHERIC LIGHT ESTIMATION

As the depth map of the input hazy image has been recovered, the distribution of the scene depth is known. Bright regions in the map stand for distant places. The top0.1 percent brightest pixels are taken in the depth map, and the pixel with highest intensity is selected in the corresponding hazy image I among these brightest pixels as the atmospheric light **A.** In most cases, a hazy image taken outdoor has a distant view that is kilometres away from the observer. In other words, the pixel belonging to the region with a distant view in the image should have a very large depth $d_{threshold}$. Assuming that every hazy image has a distant view. It is given as

$$d(x) \geq d_{thresold},\ x \in \{x|\forall y : d(y) \leq d(x)\} \qquad (8)$$

Based on this assumption, the atmospheric light **A** is given by:

$$A = I(x),\ x \in \{x|\forall y : d(y) \leq d(x)\}. \qquad (9)$$

Thus the atmospheric light can be estimated with the intensity of the pixel.

VII. SCENE RADIANCE RECOVERY

The depth of the scene *d* and the atmospheric light Aare calculated by which the medium transmission *t* is estimated to recover the scene, radiance J.

$$J(x)=\frac{I(x)-A}{t(x)}+A=\frac{I(x)-A}{e^{-\beta d(x)}}+A \qquad (10)$$

To avoid too much noise, the value of the transmission t (x) must be between 0.1 and 0.9. So the final function used for restoring the scene radiance Jin the proposed method can be expressed by:

$$J(x)=\frac{I(x)-A}{\min\{\max\{e^{-\beta d(x)},0.1\},0.9\}}+A \qquad (11)$$

Where Jis the haze free image. Thus, the haze free image can be retrieved from the proposed system.

VIII. DISSCUSSIONS AND CONCLUSIONS

In this paper, a novel linear color degradation prior, based on the difference between the brightness and the saturation of the pixels is proposed within the hazy image. By creating a linear model for the scene depth of the hazy image with this simple but powerful prior and learning the parameters of the model using a supervised learning method, the depth information can be well recovered. By means of the depth map obtained by the proposed method, the scene radiance of the hazy image can be recovered easily. Experimental results show that the proposed approach achieves dramatically high efficiency and outstanding dehazing effects as well.

Although a way is found to model the scene depth with the brightness and the saturation of the hazy image, there is still a common problem to be solved. That is,the scattering coefficient β in the atmospheric scattering model cannot be regarded as a constant in the homogeneous atmosphere conditions. For example, a region which is kilometers away from the observer should have a verylow value of β. Therefore, the dehazing algorithms which are based on the atmospheric scattering model are prone to underestimating the transmission in some cases. As almost all the existing single image dehazing algorithms are based on the constant β assumption, a more flexible model is highly desired. To overcome this challenge, some more advanced physical models can be taken into account. We leave this problem for our future research.

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