ELIMINATION OF FOG IN SINGLE IMAGE USING DARK-CHANNEL PRIOR

Vaibhav Khandelwal[1], Divyanshi Mangal[2], Naveen Kumar N.[3]

[1,2] B.Tech Student, Dept. of CSE, Vellore Institute of Technology, Vellore, Tamil Nadu, India
[3]Professor, Dept. of CSE, Vellore Institute of Technology, Vellore, Tamil Nadu, India

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Abstract - *Images that are captured in bad weather such as haze and fog are not clearly expressed and hence not so comprehensible. Such images are reduced in quality to a great degree due to the scattering of atmosphere that in turn reduces contrast and visibility. Fog lead to whiteness in the image as well as low contrast. Haze is an atmospheric occurrence which fades the clearness and precision of image because of dust or smoke which are minute portions of matter. It affects not only the visibility but also complicates post processing of image and implementation of numerous Computer Vision Algorithms. In this paper, we present efficient and productive fog elimination approach when an image is taken in as input. On the basis of estimated transmission or depth map, this procedure re-establish the hazy or foggy image. We have proposed a Dark Channel Prior approach which is beneficial for clearing the degraded image. We eliminate fog from foggy image so that the characteristics and attributes of image can be improved. At last we acquire a haze free and fog free image by this technique. The implementation and design is done with the help of MATLAB.*

***Key Words*: Dark Channel Prior; Haze; Single image defogging; Transmission map; Visibility Restoration**

1. INTRODUCTION

Outdoor images that are captured in bad weather such as haze and fog are not clearly expressed and hence they are not so understandable. This happens due to smoke, mist and dust present in the atmosphere. Such images are reduced in quality to a great extent that in turn reduces contrast and visibility. It ultimately makes it complicated to differentiate between objects. This can be critical when it comes to traffic safety, remote sensing space cameras, video surveillance, etc.

Fog removal is also known as Visibility Restoration. Removing haze and fog is a part of de-weathering problem. De-hazing is done to restore the clarity of scene by improving the contrast of images. Proposed algorithm for fog elimination makes use of Dark Channel Prior technique. Proposed technique can also be used in traffic navigation system in foggy or bad weather when the vehicles ahead are not clearly visible. This may reduce numerous accidents from happening. There are two types of techniques available- Contrast based and Physically Based Technique. The physical method is beneficial for homogeneous as well as non-homogeneous fog and haze effect. Because of this reason, we have used physical technique in the proposed paper.

Some major steps are performed in order to improve the visibility of image. First step involves the acquisition of the foggy or degraded images. Second step is the Estimation methodology which involves estimation of the scattering phenomenon and the visibility level. Third step involves the Enhancement Process that lowers the noise or fog level in the image. Final Step involves Restoration of the enhanced image.

Given fog removal algorithm takes in a single image as input. First, Fog Removal using Dark Channel Prior is done. In this step, we discuss about fog image formation model then we obtain the dark channel prior. Following this estimation of global air-light is done. Then we calculate the boundary constraints. Estimation of transition is done. In the final step, scene recovery is done. The qualitative and quantitative conclusions confirm that proposed algorithm perform better than prior algorithms as far as execution time, quality, preciseness is concerned.

The structure of given paper is depicted below:

Section 2 contains the literature survey, Section 3 discusses the fundamentals of fogging and fog removal, Section 4 discusses proposed method which is fog removal using dark channel prior, Section 5 shows the experimental results and Section 6 provides the conclusion of the study followed by references.

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2. LITERATURE SURVEY

Previous algorithms and methods for fog removal are primarily dependent on several study and observation of the same scene.

Chen, Mengyang (2009) [5] has put forward an algorithm which is iterative to balance the distortion of color affected by more saturation. The methods such as iterative matte optimization and image matting are used.

Hitam M.S et al. (2013) [6] has presented a method known as mixture contrast limited adaptive histogram equalization techniques for the improvement of images

taken underwater. The images in this paper were captured from Bidong Island and Redang Island located in Malaysia.
Xu, Haoran et al. (2012) [7] did study for a long time on the method of haze removal and came up with an evacuation algorithm. It uses fast bilateral filtering combined with dark channel prior. One more calculation is done having some enhanced estimation of transmission map.

K He et al. (2011) [8] have reached to the result that the method of dark channel prior is nothing but a kind of statistics related to outdoor de-hazed images. The extent of fog can be known and a clear defogged image can be acquired. The dark pixels give a valid estimation of the amount of fog transmission. Combination of a delicate interpolation system and haze-imaging model can give a clear fog free picture.

C.Tomasi et.al (1998) [9] proposed a method bilateral filtering. It preserves edges but smoothens the image. It is a local and simple method that is non-iterative as well. This study involves combination of different gray levels or colors based on their geometric closeness.

Yong-Qin et al. (2012) [10] have proposed an algorithm based on image filtering approach. It makes use of low-rank technique and median filter for improved visibility. Shortened single value decomposition along with dark channel prior is used to restore the defogged image. The drawback being that it suffers from halo effects. It may also not perform adequately when heavy fog is present in the scene and when there are great depth jumps.

Tarel J-P et al. (2009) [11] have proposed an algorithm based on filtering approach. It needs several parameter for adjustment and it is based on the linear operations. The main advantage is in terms of its speed. It can also be used for real time de-hazing. Moreover, a new filter is also proposed which preserves corners as well as edges. It is an alternative to median filter. The disadvantage is that the restored image is not much improved because it has discontinuities in the scene depth.

Ramesh K. et. al., (2014) [12] solves the degraded illumination complication including the foggy weather range assessment. It increases the accuracy in degraded image by application of convergence index filters. COIN filters are used in this study. The disadvantage is that the scene elements are almost same as the atmospheric light. So the directional knowledge with gradient energy magnitude is used as an additional parameter.

Xiao Chunxia et. al., [13] presented a fast defogging method from single image based on filtering. It is also associated with the depth information of underlying image. First median filtering is applied then refinement is done by joint bilateral filtering to recover the depth edge information. Final step involves utilization of atmosphere attenuation model. This method could be performed in parallel making it applicable for real time requirements.

A.K. Tripathi, et al. in 2012 [14] has formulated a method that use bilateral filter to re-establish contrast of the scene. They studied that formation of fog is due to the attenuation as well as air light. Histogram equalization method is used as preprocessing and histogram stretching is used as a post processing method.

Focus on reducing the noises in the output image must be there and hence noise reduction techniques must not be neglected.

3. FUNDAMENTALS OF FOGGING AND FOG REMOVAL

The bad weather conditions affect the visibility of outdoor images. The presence of atmospheric phenomenon like fog or haze reduce the visibility of the image. This kind of degradation in the visibility of an image is known as the hazing effect. In many computer vision applications like surveillance, automated vehicles, object recognition, these images need to be processed and the haze present needs to be removed. This process is known as haze removal from the image.

In general, the light reflected from the surface of an object is scattered by the sols present in the air such as mist, fumes, dust particles etc. before reaching the capturing device. This leads to degradation in the quality of image. The contrast is reduced and the colors become less sharp and low. This observation is significant in distant photographs taken by satellites, drones etc.

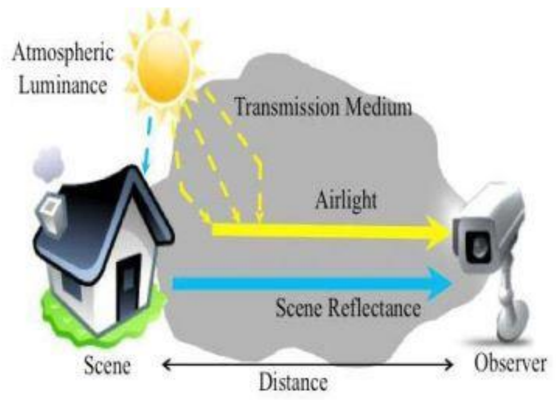


Fig-1: Atmospheric Scattering of Light

Fog Removal is very important in various fore mentioned applications and it has been a very challenging task for researchers to perform. The naïve approaches of defogging included numerous images of that specific scene taken in different climatic conditions. This approach is not efficient because of the unavailability of such information to the users.

Therefore many other algorithms and techniques are being employed for the purpose of defogging the image.

These are majorly classified into two categories: physical techniques and contrast based techniques.

(i) Physical Techniques

These techniques include estimated Transmission (depth) map, Dark channel prior, Bayesian probabilistic method and Independent Component Analysis (ICA). In these techniques image is restored by the estimation of transmission map and global air light.

(ii) Contrast based Techniques

These techniques do not employ any depth maps or air light. Instead, these methods defogs images by restoring the contrast of degraded images.

4. FOG REMOVAL USING DARK CHANNEL PRIORITIZATION

In this paper, we focus on the physical technique of defogging using dark channel prioritization.

4.1 Fog Image Formation Model

The widely used model to describe the foggy images in computer vision is as follows:

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

where,

I -> Observed Intensity

J -> Scenic Radiance

A -> Global Air light

t -> transmission within a medium representing the fraction of light reaching the camera without being scattered.

The first term on the RHS is a multiplicative term known as *direct attenuation* [1]. The other term is called *air light* [1]. The direct attenuation describes the radiance of scene and its decay in the medium. The air light is an additive distortion resulting from previously scattered light and leads to shift of scene colors [2].

In the homogenous atmosphere, the transmission is expressed as [3]:

$$t(x) = e^{-\beta d(x)} \quad ...(2)$$

Where,

β -> Scattering coefficient of atmosphere

d -> Scenic depth

The eqn. (1) implies that in RGB color space, Vectors A, J(x) and I(x) lie in the same plane and their end points are collinear. The transmission t(x) can also be represented as the ratio of two line segments [3]:

$$t(x) = \frac{||A - I(x)||}{||A - J(x)||} = \frac{A^c - I^c(x)}{A^c - J^c(x)} \quad ...(3)$$

here c is called color channel index and c ϵ {r, g, b}

The aim of defogging is the recovery of scenic radiance J(x) from the observed intensity I(x) in eqn. (1). For that we need the estimation of transmission t(x) and the global air light A. Then the scenic radiance is recovered by [2]:

$$J(x) = \frac{I(x) - A}{\max(t(x), t_0)} + A \quad ...(4)$$

where, t_0 is a very small constant (0.0001) just to avoid division by zero error. We also raise the denominator to the power of α, which is used in the fine tuning of haze effects.

4.2 Obtaining Dark Channel Prior

In most of the patches which are non-sky, one or more color channel is having some pixels whose intensity is very low or even closer to zero.

To describe dark channel more precisely, consider an image J and its dark channel, denoted by J^{dark}, is given as [2]:

$$J^{dark}(x) = \min_{y\in\Omega(x)} \left(\min_{c\in\{r,g,b\}} J^c(y) \right) \quad ...(5)$$

where, J^c is a single color channel of image J and Ω(x) is a x patch centered locally. Thus dark channel is the result of applying two minimum operators: $\min_{c\,\epsilon\,\{r,g,b\}}$ and $\min_{y\,\epsilon\,\Omega(x)}$ which is a minimum filter.

If J being outdoor fog-free image, then the intensity of dark channel of J is nearly equal to zero:

$$J^{dark} \rightarrow 0$$

We call it as *dark channel prior* [2].

4.3 Estimation of Global Air light

The global air light is used in the generation of transmission map and allow us to identify the color of atmospheric light. It is the multiplication of atmospheric luminance and the inverse of transmission map [3]. To estimate the value of A, we first need to pick up the most hazy pixel in the input image and filter each color channel by a moving window minimum filter. Then the color channel having maximum value is considered as an estimate of A [3].

4.4 Calculation of Boundary Constraint

We assume that scenic radiance J(x) of any image is always bounded from both sides, i.e.

$C_0 \leq J(x) \leq C_1$ ... (6)

In the above equation, C_0 and C_1 are two vectors having constant values related to the provided foggy image. Therefore, for any x, there is a necessity to extrapolate J(x) in the radiance cube which inflict a boundary constraint on t(x). For global air light A for every x, we can calculate the respective boundary constraint point $J_b(x)$. A lower bound on value of t(x) is calculated resulting in following boundary constraint over t(x) [3]:

$$0 \leq t_b(x) \leq t(x) \leq 1 \quad ...(7)$$

where $t_b(x)$ represents the lower bound on t(x) which is written as:

$$t_b(x) = \min\left\{max_{c\in\{r,g,b\}}\left(\frac{A^c - I^c(x)}{A^c - C_0^c}, \frac{A^c - I^c(x)}{A^c - C_1^c}\right), 1\right\} ...(8)$$

where I^c, A^c, C_0^c, and C_1^c are the color channels of I, A, C_0 and C_1 respectively [3].

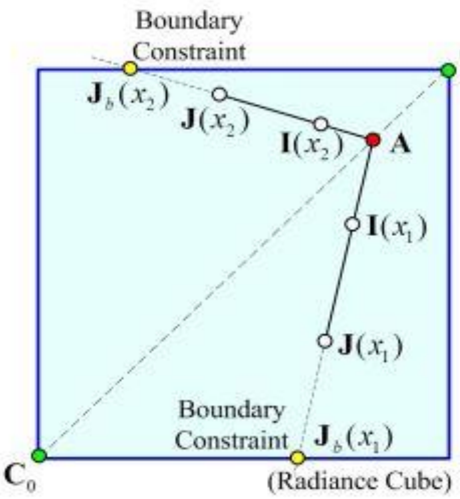


Fig-2: Radiance cube along with boundary constraint. For each x, we extrapolate J(x) which cannot cross the radiance cube's boundary. J_b(x1) and J_b(x2) are the points of boundary constraint [15].

4.5 Weighted L1 norm based regularization

Depth value is moreover constant all over the pixel in a local image. Using this assumption, we can derive patch wise transmission with the help of boundary constraints. Using weighting function over constraints, the problem of getting halo artifacts when there is abrupt change in image depth can be solved [4]:

$W(m, n)\ (t(m)\text{-}t(n)) \approx\approx 0$ ... (9)

Where m, n are neighboring pixels and W(m,n) acts as kind of a switch between constraints of m,n.

i.e. when W(m,n) = 0 => contextual constraints of t(x), of m,n is cancelled. The bigger challenge is to find the value of W(m,n) because it totally depends upon the image depth. More precisely, it is inversely proportional to the image depth i.e. when depth between m and n is small, W(m,n) is large and when depth is very small then W(m,n) tends to zero. Due to lack of information about depth, t(x) can not be constructed using depth map. We know that pixel having same intensity and color share similar depth. Hence using color and intensity difference we give a weighting function [4]:

$$w(m,n) = e^{-||I(m)-J(n)||^2 / 2\rho^2} \quad ...(10)$$

ρ is a prescribed parameter. Integrating weight function over whole image we get following contextual regularization on t(x):

$$\int_{m\in\Omega}\int_{y\in} w(m,n)|t(m) - y(y)|dmdn \quad ...(11)$$

Where Ω represents domain of image. On discretizing eq. (11) we obtain:

$$\sum_{i\in I}\sum_{j\in w_i} w_{ij}|t_i - t_j| \quad ...(12)$$

On introducing set of differential operators on eq. (11), we obtain:

$$\sum_{j\in w}\left|\left|W_j^o(D_j \otimes t)\right|\right| \quad ...(13)$$

where ω denotes index set, ∘ operator denotes the element-by-element multiplication, ⊗ denotes the convolution operator, D*j* is a differential operator of first-order, W*j* (j ∈ω) represents weighting matrix.

Fig.4 has a collection of differential filters of high-order that can be used on eq.(13) [15].

4.6 Estimating The Transmission

The method of estimation of transmission assumes that the transmission within a patch Q(x) has constant value locally. We represent the transmission of patch as l(x). Applying the minimum operation in local patch gives [16]:

$$\min_{y\in\Omega(x)}(I^c(y)) = t(x)\min_{y\in\Omega(x)}(J^c(y)) + (1 - t(x))A^c \quad ...(14)$$

The operator is applied on all the channels independently. The estimated transmission map from a haze image is roughly good but it has some block effects since transmission is not always constant with in a patch.

4.7 Scene Recovery

The value of J(x) is finally obtained by eq.4. The obtained scene J is very vulnerable to noise. So we bound t(x) to a lower bound t_0 , which implies that a small amount of fog is sustained in highly dense foggy regions[16].

5. EXPERIMENTAL RESULTS

Fig.3. shows some example of our defogging results obtained from our program which is written in Matlab.

We have used all the steps sequentially to program the proposed algorithm of defogging by dark prior. The output images clearly shows the dark channel prior of the input image, the transmission (depth) map and the output defogged image.

The dark channel is obtained by using eq, (4) then the global air light is estimated. The Boundary constraints are calculated by eq. (8) , the transmission is calculated by section 4.5 and the filters discussed in section 4.4 (Fig. 4). Finally, the defogged image is recovered as discussed in section 4.6.

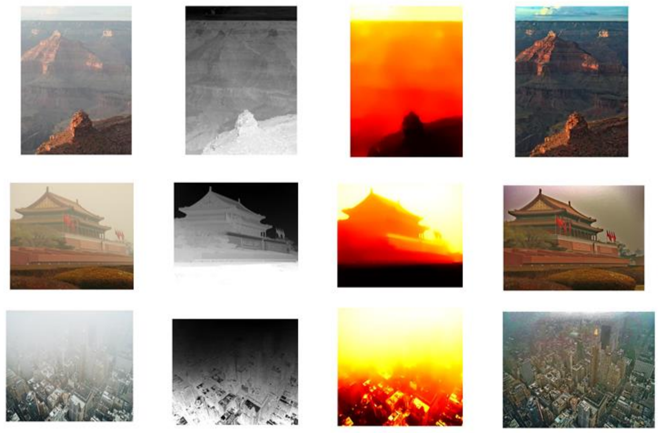
As it can be clearly seen from Fig.3 that our algorithm unveils fine details from the foggy image which are not visible from the original foggy images. The global air light is self – estimated by the brightest pixel but if sky is included in images, some distortions can be there because of the intensity of sky pixels. For all other cases the program works perfectly matching with our intentions.

6. CONCLUSIONS

In the above presented paper, we have put forward an easy and powerful defogging technique, dark channel prioritization. Fog removal algorithms are becoming more and more useful these days for several processing and vision applications. One of the main problems in processing is the smoke, fog, haze which results in reduction of contrast of the images. Distinction of objects thus becomes complex. Bad Weather conditions decreases the operation range of many processes.

Combining dark channel prior with the degraded image model, haze elimination from single image becomes more effective and even simpler.

Our method merely depends upon haze imaging model (section 4.1), it may fail to work if the model is physically invalid. It can also wrongly estimate the dark channel prior for the images having objects with color more similar to that of sky e.g. white marble. Some failure cases of dark channel prior and haze model are shown in Fig.5 and Fig.6 respectively. For all color channels, the haze/degraded imaging model eq. (1) supposes a common transmission. Our procedure may not be able to retrieve the actual scenic radiance of far-away elements. That is why they stay bluish colored. Further research on this topic can be done in future.



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

Fig-3: Haze Removal Results by the Algorithm.

(a)Original Images; (b) Corresponding Dark Channel Prior; (c) Recovered Depth Maps; (d) Output defogged Images

-3	-3	-3
-3	0	5
-3	5	5

-3	-3	-3
-3	0	-3
5	5	5

-3	-3	-3
5	0	-3
5	5	-3

-3	-3	5
-3	0	5
-3	-3	5

-1	-1	-1
-1	8	-1
-1	-1	-1

5	-3	-3
5	0	-3
5	-3	-3

-3	5	5
-3	0	5
-3	-3	-3

5	5	5
-3	0	-3
-3	-3	-3

5	5	-3
5	0	-3
-3	-3	-3

Fig-4: A collection of high-order processing filters utilized in the given study which is composed of one Laplacian operator as well as eight Kirsch operators in order to maintain the corners and edges of image.

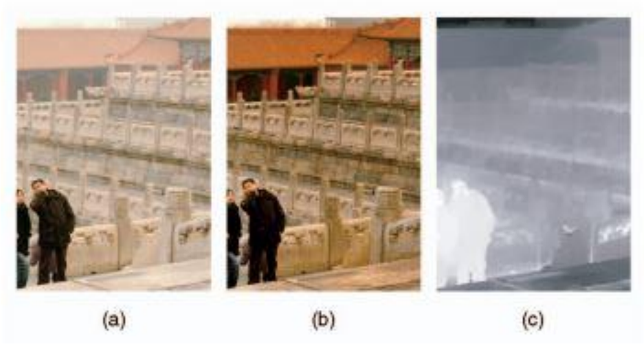


Fig-5: Dark channel prior failure cases; (a) Foggy picture; (b) Result of the study; (c) Recovered transmission map. Marble's transmission estimated too low.

Fig-6: Haze imaging model failure case; (a) foggy image; (b) Result of the study; (c) Dark channel; (d) Estimated transmission map.

Note: The points where the atmospheric light is calculated are represented using Red pixels.

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