Single image haze removal using variable fog-weight

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Abstract – In this paper, a new Image Haze Removal technique is proposed using variable fog-weight. The objective of the proposed technique is to improve the visibility, to remove the impact of weather factors and make image more usable. To achieve this, it is required to estimate the transmission map as well as atmospheric light by using Dark Channel Prior. The main contribution in this work, is to vary the fog-weight during transmission estimation. It is varied according to the density of haze in the input image. If the density of the haze in the input image is low, then lower fog-weight value will be applied and if the haze density in the input image is higher, than higher fog-weight value will be applied, according to the haze concentration. A guided filter is used as a refiner of transmission map to avoid the halo artifacts at the boundary of the edge. It provides smoothness to the image and build-up the visibility of the image, so that we restore a superior haze free image. At last, the performance of the proposed method is compared with some of the existing methods in terms of visibility, computational time and avoidance of halo effect.

1. Introduction

The quality of an image is generally degraded due to poor weather condition and presence of suspended particle like fog, mist, dust and haze in the atmosphere. So, the incoming light towards the image capturing device is attenuated and the contrast of the image is degraded. Therefore, the dehazing of the image is needed to overcome the impact this unwanted weather factors. Image dehazing is the procedure to extract the haze impact from the degraded captured image and reconstruct the original colours of the degraded image. Reconstruction of original colour of the degraded image, captured under bad weather condition is extremely desired in both computational photography as well as computer vision applications. Therefore, the extraction of haze from the captured image is most challenging tasks. During the past decade, many numbers of researchers have made efforts and they developed the methods to extract haze from the degraded captured image.

In order to extract the haze from captured image, there are enormous numbers of Haze Removal have been introduced. Earlier haze removal [1, 2] were based on multiple number of images of the same scene or additional supplements. These methods, improve visibility of degraded images and provide better results, but they are time consuming and tough to carry out due to their acquisition steps.

Another approach for improving the quality of degraded images are polarization-based techniques [3-6]. These methods were used the difference of multiple images of the coequal scene captured under...
the different polarization degrees and provide an impressive restored image, but in real time, it is very tough to take minimum and maximum polarization degrees under the coequal scene. So, these methods are incompatible for the reconstructions of images. Another category of method Deep Photo [7] is a more decisive system introduced by J. Kopf et al. that is based on digital geography and urban structures that are current geo-referenced. The digital method of authentication has been used in this model to change the image. To restore the image using multiple images based Haze Removal are very difficult, time consuming and inappropriate.

To expel the disadvantage of multiple image based dehazing techniques, single image based dehazing techniques were presented. Under the assumption that, the hazy image has lower contrast in comparison to the original haze-free image, Kim et al. [8] and Tan [9] proposed haze removal techniques to recover the original haze-free image by enhancing the local contrast. These methods provide impressive results and also can be used for grayscale dehazing, but the produce images were over-saturated. Schaul et al. [10] and Tarel and Hautiere [11] were also used contrast enhancement-based techniques to remove the haze effect from the hazy images and used preserving filter to preserve the corner and edge of the images, but over saturation problem in the restored image were still there. R. Fattal [12] introduced a haze removal technique to restore the contrast of hazy images under the assumption that there is un-correlation between transmission medium and surface shading. For the estimation of transmission map, they used Independent Component Analysis (ICA) and Markov Random Field (MRF) model.

After a great deal of analysis on haze free image, He et al. [13] discover an effective dark channel prior (DCP) based image dehazing technique to restore the dehaze image from the single hazy image. They claimed that DCP is the statistical based observation of haze free image and the approach of DCP is: for most of the non-sky region, at least one colour channel of RGB (red, green, blue) space has a few pixels whose intensity near zero. By using soft matting filter they refine the transmission map to reduce the halo artifact from restored image and improve the quality of the image. However, due to the use of soft matting, this algorithm became time consuming. Recently, a lot of researchers tried to improve the time complexity problem caused by using soft matting and made efforts such as, haze removal based on median filter [14], smoothing filter [15], guided filter [16], He et al. himself replace the soft matting with guided filter [17] and Kim et al. [18] removed soft matting with some modification in transmission map. By using these techniques, time complexity problem decreased, but the halo artifact in the image also in occurred.

To solve the halo artifact, Wang et al. [19] presented layered total variation (LTV) regulariser, multichannel total variation (MTV) regulariser, and colour total variation (CTV) regulariser based model combining with TVs and DCP models to restore haze free image. Xu et al. [20] proposed DPC and guided-filter based algorithm and to avoid the halo effect and incorrect transmission map in DCP, they used Local Adaptive Template approach. The estimation of medium transmission map based on the saturation of the image was reported by Kim et al. [21]. In this method, they assumed that transmission of the local patch cannot be constant and it varies from pixel to pixel. The speed of this algorithm was fast and provide gratified dehaze image, but in case of heavy haze, it is failed to provide satisfied output.

In this paper, a DCP based haze removal with modified transmission map has been proposed which is based on variable fog-weight. In this proposed work, the main focus is to reduce the time complexity, minimizing the halo artifact and improve the visibility of the input image. The main Contribution of the proposed framework is to vary the fog weight and to modify the inaccurate transmission map in DCP depending on the haze density of the input hazy image. After modifying the transmission map, a guided filter is used to avoid the halo artifact up to the threshold which results a high-quality haze free image.

The rest part of this paper is given as follows. Section 2 represents a brief review of related work. The Proposed work is presented in section-3. Experimental results and analysis are discussed in section 4 and concluding remarks are presented in section-5.
2. Related Work

2.1 Atmospheric Scattering Model

The behaviour of incoming light towards the image capturing device is defined by the basic laws of physics. First, light is reflected from an object towards the image capturing device, is attenuated by the atmosphere, including the presence of suspended particle like fog, dust, mist and haze. Likewise, light coming from different light sources is scattered towards the image capturing device and causes a shift in colour. These phenomena increase with an increase in distance between the object and the image capturing device. Meanwhile, haze removal requires the detection of hazy areas in an original image and appropriate extraction to the degree of haze, which can be described as the process of removing the haze from the haze-affected areas.

To describe the hazy image, the atmospheric scattering model, which is proposed by McCartney in 1976 [22], is generally utilized in computer vision and image processing and the model can be show as follows:

\[ H(x) = S(x)T(x) + A(1 - T(x)) \]  

\[ T(x) = e^{-\beta d(x)} \]

In equation (1), \( x \) is the location of the pixels in the image, \( H \) denote the intensity of the captured hazy image, \( S \) denote the scene radiance representing the reconstructed haze-free image, \( A \) denote the global atmospheric light and \( T \) denote the transmission map. \( H, S, \) and \( A \), all are three-dimensional vector in RGB space. Since \( H \) is known parameter in equation (1), the target for removing haze from the \( H \) is to estimate the transmission map \( T \), atmospheric light \( A \), then recover the \( S \) with the help of equation (1). The atmospheric scattering model contains two parts. The first part \( S(x)T(x) \) is known as direct attenuation. The first part represents un-refracted part of the light reflecting from scene point towards the image capturing device. The second part \( A(1 - T(x)) \) is known as air-light. The second part represents atmospheric reflected environmental illumination involved in the captured hazy image. When the atmosphere is homogenous, the transmission map \( T \) can be expressed as:

\[ T(x) = e^{-\beta d(x)} \]

Where \( \beta \) is the scattering coefficient of the atmosphere. \( d \) is the distance between scene point and image capturing device and known as scene depth. The equation (2) indicates that scene radiance in attenuated exponentially with the scene depth.

2.2 Dark Channel Prior

In equation (1), the calculated transmission map \( T \) and atmospheric light \( A \) is the most significant component to reconstruct the haze-free image \( S \). For solving the equation (1), the DCP statistics proposed by He et al. [13] has been used to estimate the atmospheric light \( A \) and transmission map \( T \). DCP is focused on statistical measurements of various out-of-door haze-free images. They found that haze-free images consist of a few pixels that have very small intensities in at least one colour channel in the most of the non-sky areas.

In the DCP, lower intensities are mainly by cause of three factors: a) Shadow e.g. shadow of car, building, tree, and rocks; b) Colourful item e.g. green grass, tree, plants, colourful flowers, leaf, and the water surface; C) Dark objects e.g. dark tree trunk and stone. Formally, for image \( S \), DCP may be expressed as:

\[ S_{\text{dark}}(x) = \min_{c \in \{r, g, b\}} \left( \min_{y \in \Omega(x)} (S^c(y)) \right) \]

Where \( S^c \) is the color channel of \( S \) and \( \Omega(x) \) is local patch centred at \( x \). The DCP observation says that except for sky region, the intensity of \( S_{\text{dark}} \) is very low and tends to be zero.
2.3 Estimation of Transmission Map

He et al [13] presume that atmospheric light $A$ is known and provided an automated process for measuring atmospheric light $A$. They additionally presume that transmission within the local patch is constant and transmission within the local patch $\Omega(x)$ is defined as $\hat{T}$. They considered this local patch size as $15 \times 15$. By employing min operation in the local patch and taking min operation in colour channels (r, g, b) on Equation (1), the transmission $\hat{T}$ may be expressed as:

$$\hat{T}(x) = 1 - \min_c \left( \min_{y \in \Omega(x)} \left( \frac{H_c(y)}{A_c} \right) \right)$$

(4)

In fact, it cannot be assumed that on a clear day, there is no particle in the atmosphere. So, there is some haze is existent for a distant object and the haze is the basic indicator of a person’s perception to identify the depth. So, a constant parameter $\omega$ was introduced in equation (4).

$$\hat{T}(x) = 1 - \omega \min_c \left( \min_{y \in \Omega(x)} \left( \frac{H_c(y)}{A_c} \right) \right)$$

(5)

He et al. [13] fixed the value of $\omega$ to 0.95 for all results. He et al. [13] used patch size as $15 \times 15$ and the result is reasonably good, but some block effect appears in the output. Therefore, to avoid the block effect, they used soft matting as a refiner of transmission map and provide an impressive dehaze image. But this technique is time consuming. In another model, He et al. himself replace soft matting with a guided filter to reduce the computation time, but in many of the images, this model failed to avoid the block effect [17].

3. Proposed Work

The details of novel proposed technique are presented in this section. Figure 1 represents the block diagram of our proposed work.

![Flow Chart of the proposed algorithm.](image)

In this proposed work, the dark channel prior statistic has been followed to dehaze the input image which has discussed in subsection 2.2. Using this DCP statistics, estimation of the atmospheric light has been done which is presented in subsection 3.4, and modified transmission map is presented in subsection 3.2. To remove the block effect and improve the quality of the image, guided filter is used and discussed in subsection 3.3. Finally, a high-quality haze free is obtained by recovering the scene radiance and that is discussed in subsection 3.5.
3.1 Steps to Implement the Method

Input: Hazy Image (H).
Output: Haze Free Image (S).

1. Obtain the DCP Statistics ($S_{dark}$).
2. Estimate the atmospheric light (A) with the help of $S_{dark}$.
3. Estimate the transmission map (T) using A and $S_{dark}$.
4. Refine the transmission map (T) using Guided Filter.
5. Recover the dehaze Image (S) using A, T and H.

3.2 Modified Transmission Map Estimation

In this model, the DCP statistic algorithm is first used to dehaze the image. The atmospheric light A is estimated with the help of DCP statistic algorithm and then used the result of this estimated atmospheric light A in the estimation of transmission map. The modified transmission map using DCP statistic is represented as:

$$
\hat{T}(x) = 1 - \omega_{vr} \min_c \left( \min_{y \in \Omega(x)} \left( \frac{H_c(y)}{A_c} \right) \right)
$$

(6)

Here $\omega_{vr}$ Represents the variable fog weight. He et al. [13] fixed the value of this parameter to 0.95 for all the results. Another model, proposed by Kim [18], fixed it to 0.8 for all the results.

After doing a lot of practical analysis of different types of images, it is found that the value of fog-weight can’t be fixed for every image and it is varied from 0.6 to 1. So, the variable fog-weight can be expressed as:

$$
\omega_{vr} = \log_{10} R \quad 4 \leq R \leq 10
$$

(7)

Here R is the real number and it can be taken any value from 4 to 10.

In case of light hazy images, the value of variable fog-weight $\omega_{vr}$ is varied from 0.6 to 0.8 and in case of dense hazy images, it is varied from 0.8 to 1. However, the transmission obtained from equation (6) will not match the edge of the input image and some block effect occurs.

![Figure 2. Comparison of transmission map. (a) Input hazy image. (b) Transmission map of He et al. (c) Transmission map of proposed work.](image-url)
of the edge is also increased. If the patch size is small (1 × 1) the block effect is completely removed, but image become over saturated and blurred. Therefore, the patch size for the transmission is considered as 7 × 7 for all the results. Due to the variable fog-weight, saturation is also under controlled. Figure 2 shows the comparative output of transmission map of proposed work with He et al. transmission map.

However, consideration of patch size as 7 × 7 decreases the block effect very much, but in some images, a very small amount of block effect at boundary of the edge is still occurred. Therefore, a refinement process of transmission map is needed to avoid the block effect completely. Here, a fast speed refinement filter that is guided filter is used to avoid the block effect completely and provide smoothness in the recovered image.

3.3 Guided Filter

To refine the transmission map, He et al. [13] used Soft Matting technique, but Guided Filter is used to refine the transmission map in this paper. It requires less computation time and provide more smooth result as compared to soft matting technique. Guided filter is a type of edge preservative smoothing that filters the input image under another guidance image. It is an efficient way of refining the transmission map.

Considering the guidance image is H, p is an image to be filtered and q is resulting image. The local linear model of the Guided Filter is given as:

\[ q_i = a_k H_i + b_k, \quad i \in \omega_k \]  \hspace{1cm} (8)

Where \( \omega_k \) is a window centred at pixel \( k \), with radius \( r \), and \( a_k, b_k \) are known to be linear coefficient and these are set values in the window \( \omega_k \) which is the basic prerequisite for defining the formula. The weighted-average filters used to find the linear filter in the form of:

\[ \nabla q = a \nabla H \]  \hspace{1cm} (9)

Solution of the filtering result is equal to the minimized equation of following cost function:

\[ E(a_k, b_k) = \sum_{i \in \omega_k} ((a_k H_i + b_k - p_i)^2 + \varepsilon a_k^2) \]  \hspace{1cm} (10)

Here, \( \varepsilon \) is known to be a regularization parameter which is used for rounding off the large \( a_k \). The equation (10) is called as a linear ridge regression model and its solution can be found by:

\[ a_k = \frac{1}{|\omega|} \sum_{i \in \omega_k} \mu_i p_i - \mu_k \bar{p}_k }{ \sigma_k^2 + \varepsilon} \]  \hspace{1cm} (11)

\[ b_k = \bar{p}_k - a_k \mu_k \]  \hspace{1cm} (12)

Here, \( \mu_k \) and \( \sigma_k^2 \) denote the mean and variance of H in window \( \omega_k \) respectively, \( |\omega| \) denote the total number of pixels in the window and \( \bar{p}_k = \frac{1}{|\omega|} \sum_{i \in \omega_k} p_i \) denote the mean of \( p_i \) in the window. With the help of equation (11) and equation (12), we can find the output \( q_i \) by equation (8).

However, at the time of determining linear coefficients, one pixel may be involved in multiple windows, means, each pixel can be defined by more than one linear function. Therefore, to calculate the filtering output value at a point, we need to averages all the possible values of \( q \) that contain at that point, as follows:
\[ q_i = \frac{1}{|\omega|} \sum_{k:i \in \omega_k} (a_k H_i + b_k) \]  

(13)

Due to symmetry, \( \sum_{k:i \in \omega_k} a_k = \sum_{k:i \in \omega_i} a_k \). So, the equation (13) can be written as:

\[ q_i = \bar{a}_i H_i + \bar{b}_i \]  

(14)

Here, \( \bar{a}_i = \frac{1}{|\omega|} \sum_{k \in \omega_i} a_k \) and \( \bar{b}_k = \frac{1}{|\omega|} \sum_{k \in \omega_l} b_k \) denote the average coefficient of all the windows overlapping \( i \).

### 3.4 Estimation of Atmospheric Light

In most of the earlier methods for removing haze, the atmospheric light has been guessed by the most of the hazy pixels. The pixels of the maximum intensity have been regarded as atmospheric light by Tan et al. [9] and is further refined by R. Fattal [12]. Yet the brightest pixel of actual image may be on white objects. The dark channel of the hazy image can approximate the haze thickness properly. So, the dark channel prior can be employed to estimate the atmospheric light \( A \) accurately [13]. In the proposed method, the top 0.1% brightest pixels in the dark channel are picked. In such pixels, the highest intensity pixels are elected as atmospheric light in the hazy image.

### 3.5 Scene Radiance Recovery

As it is discussed in subsection 2.1, if atmospheric light \( A \) and transmission map \( T \) will be determined then the recovery of scene radiance \( S \) can be done from the equation (1). The atmospheric light \( A \) is already estimated that is shown in subsection 3.4. The transmission map and refined transmission map with guided filter is also estimated. But the attenuation \( S(x)T(x) \) may be approximate to zero if transmission \( T(x) \) approximates to zero. The directly restored scene radiance \( S \) in prone to noise. So, transmission \( T(x) \) is confined to a lower bound \( T_0 \) and this lower bound is taken as 0.1 in this paper.

The final scene radiance \( S(x) \) may be recovered by:

\[ S(x) = \frac{H(x) - A}{\max(T(x), T_0)} + A \]  

(15)

### 4. Experimental Results and Discussion

The visibility restoration of single hazy image in this haze removal algorithm is controlled by two parameters: first one is patch size, which considered by us in this haze removal method as \( 7 \times 7 \). Its contribution in this haze removal is to minimize the halo artifact. Second one is variable fog-weight \( \omega_{vr} \), which is varied according to the haze density of the input image.

#### 4.1 Qualitative Comparison

In this subsection, the performance of the proposed method is compared with existing techniques like DCP with guided filter, DCP with soft matting filter proposed by He et al. [13, 17] in terms of visibility. The proposed method produces the best results in comparison to the above methods. Figure 3 shows the comparison of results of He et al. [13] to the proposed method results without using filter, that is, the results without refining the transmission map. It can be seen that without refining the transmission, in proposed method results, halo artifact is less than He et al.

Figure 4 and Figure 5 show the comparative results of the proposed algorithm to results of He et al. [13, 17]. From this figure, it has been noticed that, the estimated transmission map in He’s method is affected by the haze effect at the boundary of the edge. In soft-matting based method, blurred effect is observed in the recovered image, especially the areas where the depth is rapidly changing into the image. It seems that a layer of haze is still present in the image. The results of the DCP+GF based method, is highly affected by block effect. In proposed algorithm, the modified transmission map calculates the
more accurate transmission at the boundary of the edge and effectively avoid the halo effect. The proposed algorithm provides more clear and sharp result in compare to DCP+GF result and He’s soft-matting based results and provides relatively excellent performance.

Figure 3. Comparison of results without refine the transmission map by any filter. (a) Input hazy image (b) output of He et al. without refining the transmission map. (c) Proposed method results without refining the transmission map.

Figure 4. Comparison of different algorithms using image-1 and image-2 (a) Input hazy images. (b) Output results of DCP+GF (c) Output of Soft-matting based method of He et al. (d) Output of proposed algorithm.
4.2 Computation Time

The proposed algorithm is executed using MATLAB R2019a with Intel Core i5-8265U CPU @ 3.40GHz and 8GB RAM. The performance of the proposed algorithm is compared with existing algorithm like soft-matting based algorithm proposed by He et al. [13] and DCP+GF based algorithm in terms of computation time. The computation time for different techniques with different size images are given in Table 1. From this table, it has been observed that, the proposed method is much faster than existing techniques.

| Images | He et al. | DCP+GF | Proposed method |
|--------|-----------|--------|-----------------|
| image-1 | 5.373     | 0.697  | 0.388           |
| image-2 | 9.888     | 1.233  | 0.681           |
| image-3 | 15.916    | 1.898  | 1.060           |
| image-4 | 23.614    | 2.468  | 1.486           |
| image-5 | 33.653    | 3.315  | 2.024           |
| image-6 | 42.861    | 4.733  | 2.601           |
| image-7 | 61.726    | 5.545  | 3.299           |
| image-8 | 80.144    | 6.804  | 4.029           |

5. Conclusions

In this paper, a fast and effective single image haze removal algorithm is presented to dehaze the hazy images. In this algorithm, the authors mainly focused on avoiding block effect at the boundary of the edge and modify the transmission map to provide haze free image, even when haze density is low or high in the hazy image. In this proposed method, the atmospheric light and transmission map has been estimated using DCP approach and modified the transmission map using fixed patch size and proposed variable fog-weight \( \omega_{vr} \). A fixed patch size of \( 7 \times 7 \) is taken for all the images to minimize the block effect. The values of \( \omega_{vr} \) is varied according to the haze density of the input image. For a haze free output, the value of \( \omega_{vr} \) is varied between 0.6 To 1. To avoid the halo effect up to the threshold level and providing smoothness to the restored image, the authors refined the transmission map using guided...
filter. After experiments on different type of haze image, it is confirmed that our algorithm can accurately estimate the transmission map and effectively avoid the block effect. In addition, the proposed algorithm is compared with some existing methods in terms of visibility and computational time. From a qualitative analysis and computational time and block effect analysis, it can be concluded that, the proposed method performs superior over the discussed existing techniques.

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