



Image Haze Removal Techniques – A Personal Perspective and Assessment

Ms. Lakshmi Raj
P.G Scholar

Department of Computer Science & Engineering
FISAT, Mookkannoor, Kerala, India

Ms. Reshmi R

Assistant Professor

Department of Computer Science & Engineering
FISAT, Mookkannoor, Kerala, India

Abstract: Image haze removal has become an important research direction in the field of computer vision because of the vast development and increasing demand of its applications. In the present era, where uploading images in social media has become very common, the image editing and processing applications has gained much popularity. Outdoor images that are captured in bad weather are seriously degraded due to several factors. Haze, being the most common degrading factor, affects the visibility of the images and makes them unclear. Haze is formed due to a combination of two fundamental phenomena namely, attenuation and airlight. Attenuation deteriorates the scene contrast and air light increases the whiteness in the scene. Therefore, the removal of attenuation and airlight helps to restore the color and contrast of the images, making them haze-free. Different works have been proposed till date in order to filter out haze from images. This paper analyses the different image haze removal techniques. The different techniques, along with their merits and demerits are discussed.

Keywords: Atmospheric Scattering Model ; Dehazing ; Haze removal ; Image Processing ; Image restoration ; Scene radiance recovery ;

I. INTRODUCTION

Haze is an atmospheric phenomenon that affects the clarity of the sky. Haze mainly constitutes of aerosols which are dispersed systems of small particles suspended in air. Haze comes from many different sources such as combustion products, volcanic ashes and foliage exudation. The particles produced by these sources quickly respond to the changes in relative humidity. When the humidity is high, these particles act as nuclei of small water droplets, resulting in the formation of haze. Haze particles are larger than air molecules but smaller than fog droplets. Haze also produces a distinctive bluish or greyish color shade in images and will certainly affect the visibility of images.

When capturing an image of an object in the haze-free condition, the object to be captured reflects the energy from the illumination source (e.g., direct sunlight, diffuse skylight and light reflected by the ground) and only a little amount of energy is lost when it reaches the imaging system. The imaging system collects the incoming energy reflected from the object and focuses it onto the image plane. Hence, a clear image is obtained. Without the influence of the haze, outdoor images are usually with vivid color. But in hazy weather, the situation becomes more complex. There are two mechanisms in imaging under hazy weather, which causes the captured image to be unclear. First is the direct attenuation which is caused by the reduction in reflected energy. The other is the white or gray airlight, which is formed by the scattering of the environmental illumination. Since the haze concentration changes from place to place, it is difficult to detect haze in an image. The images captured under haze undergo degradation, loses fidelity and becomes less visible. Haze may also cause annoyance to commercial and artistic photographers. Image haze removal is thus a challenging task. This paper gives a detailed analysis on various image haze removal techniques.

The remainder of this paper is organized as follows: Section II introduces the atmospheric scattering model briefly

and reviews the types of haze removal methods. Related works in the literature of image haze removal are analyzed in Section III. Finally, a brief conclusion is given in Section IV.

II. BACKGROUND DETAILS

The atmospheric scattering model [1] widely and commonly used to describe the formation of a hazy image can be described as in (1).

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

where x is the pixel position, I is the hazy image, J is the scene radiance representing the haze-free image, A is the atmospheric light (also called airlight), and t is the medium transmission indicating the portion of the light that reaches the camera without getting scattered. The major goal of image haze removal is to recover a haze-free image J , by finding the airlight, A , and transmission, t , from the received input image I . In this model, the term $J(x) \cdot t(x)$ is called direct attenuation and the term $A(1 - t(x))$ is called airlight.

The **haze removal techniques** can be classified into two categories namely, multiple image dehazing techniques and single image dehazing techniques. Multiple image dehazing technique uses multiple images of the same scene for haze removal. This method attains known variables and avoids the unknowns. Single image dehazing technique requires only a single input image for haze removal. It relies upon statistical assumptions and/or the nature of the scene. The scene information is recovered based on the prior information from a single image. This technique is becoming more and more of researcher's interest. Some of the popular techniques falling under these two categories of image haze removal are described below.

A. Techniques based on different weather conditions

This approach uses multiple images taken under different weather conditions [2]. The basic idea is to compare the

differences of two or more images of the same scene. The properties of the contributing medium will differ in images taken under different weather condition. This approach can significantly improve visibility. But one needs to wait until the properties of the medium change. Thus, this approach is inefficient to deliver the result instantly for scenes that have never been met before. Moreover, this approach cannot be used to handle dynamic scenes.

B. Techniques based on Polarization

This approach uses two or more images of the same scene which are taken at different angles with a polarizer [4]. The basic idea is to take multiple images of the same scene that have different degrees of polarization. The different degrees are obtained by rotating the polarizing filter attached to the camera. But this approach cannot be applied to dynamic scenes for which the changes are more rapid than the filter rotation. In addition, special equipments like polarizers are needed for the dehazing process. The outputs produced are not satisfactory.

C. Depth Map based techniques

This approach uses the depth information for haze removal [14]. The approach uses a single image and is based on certain assumptions. First assumption is that the 3D geometrical model of the scene is provided by some databases such as from Google Maps. Second assumption is that the texture of the scene is given (from satellite or aerial photos). This 3D model is then aligned with hazy image, which provides the scene depth. This technique does not require any special equipment. User interaction is required to align 3D model with the scene, which provides accurate results. Its shortcoming is that it is not automatic, it needs user interactions. The approach requires the estimation of more parameters, and the additional information is difficult to obtain.

D. Dark Channel Prior techniques

This is a single image dehazing method. The dark channel prior [9] is a type of statistics of the outdoor haze-free images. In most of the non-sky patches, at least one color channel has zero or very low intensity values for some pixels. These pixels are called dark pixels. These dark pixels are used for the estimation of transmission map. The airlight is estimated by picking up the pixels in the input image corresponding to the top 0.1% brightest pixels in the dark channel, and then choosing the pixel with higher intensity. The scene radiance can be finally derived by using the airlight and transmission. This approach is physically valid and works well in dense haze. But when the scene objects are similar to airlight, the approach becomes invalid.

E. Techniques based on Markov Random Field(MRF)

This approach comes under single image dehazing. In this approach, the haze removal is done by maximizing the brightness of the image based on Markov Random Field (MRF) [7]. It is a graphical model of joint probability distribution. It consists of an undirected graph with each node representing a random variable. The approach is based on two observations. First, the images taken on a clear day have a higher contrast compared to images taken in bad weather. Second observation is based on airlight, which varies with the distance between the objects and the observer.

F. Contrast Maximization techniques

This is a single image dehazing method. Haze diminishes the contrast of an image. Thus dehazing is done to improve the visibility of the image by enhancing its contrast. Contrast maximization [6] is a technique that enhances the contrast of an image under certain constraints. The resultant images have higher saturation values because this approach does not physically improve the brightness or depth, but only enhance the visibility. The output images also contain halo effects at depth discontinuities.

G. Techniques using Independent Components Analysis

Independent Components Analysis [5] requires only a single image for haze removal. It is a statistical approach to separate two additive components from a signal. The haze removal is done based on the assumption that the surface shading and transmission are statistically uncorrelated in local patch. This approach is physically valid and can produce better results, but is considered unreliable as it does not work well in images containing dense haze.

H. Techniques using Anisotropic Diffusion

Anisotropic diffusion is a single image haze removal technique without removing the image features such as lines, edges or other properties that are essential for the understanding of the image. This approach [17] is flexible in that it permits to combine smoothing properties with image enhancement. Anisotropic diffusion can be used to refine air light from dark channel prior. Anisotropic diffusion is used to smooth the airlight map. It performs well in images with heavy haze.

III. RELATED WORKS

This section gives an analysis on the various works that have been proposed in the area of image haze removal, stating both their merits and demerits.

Two fundamental scattering models - airlight model and attenuation model are described in [2]. The paper also develops methods for recovering scene properties, such as three dimensional structures from multiple images taken under poor weather conditions. Then, the chromatic effects of the atmospheric scattering are modelled and it is verified for haze. Based on this chromatic model, several geometric constraints are derived on scene color changes that are caused by varying atmospheric conditions. Finally, using these constraints, algorithms are developed for computing haze color, depth segmentation, three dimensional structure extraction, and recovering clear day scene colors from two or more images taken under different but unknown weather conditions. This technique provides better visibility of images but, it requires a clear day image of the scene to perform dehazing.

Later, the question of (de)weathering a single image is addressed using simple additional information provided interactively by the user in [3]. The work focused on the physics-based models where the authors have developed three interactive algorithms to remove weather effects from, and add weather effects to, a single image. The authors have used a method called dichromatic color transfer for color restoration

in color images. Another method called depth heuristics is also used for color restoration in both gray and color images. Using only a single input image, a better output is produced compared to the previous methods. But the efficiency of the output depends on the user input.

As a development of the work described above, an approach for easily removing the effects of haze from passively acquired images is presented in [4]. The approach is based on the fact that, the natural illuminating light scattered by atmospheric particles (airlight) is partially polarized. The method stems from physics-based analysis, so even if the polarization is low, it works under a wide range of atmospheric and viewing conditions. The approach does not rely on scattering models such as Rayleigh scattering. It can be used with as few as two images taken through a polarizer at different orientations. The method also yields a range map of the scene, which enables a scene rendering as if imaged from different viewpoints. It also provides information about the atmospheric particles. The technique obtains a great improvement of scene contrast and correction of color. But, stability decreases as the degree of polarization decreases. Moreover, this technique does not work in images without sky region.

Reference [5] derives an approach for recovering a parameter (degree of polarization) needed for separating the airlight from the transmission, thus recovering contrast without any user interaction or existence of the sky in the frame. This technique is physics-based, rather than being pure Independent Components Analysis (ICA) of mathematically abstract signals. The technique was successful in estimating the blind parameter efficiently and dehazing using this method showed significant improvement of visibility and color, relative to the raw data. But, some images were over saturated.

A scheme for an adaptive image contrast enhancement based on a generalization of histogram equalization (HE) is proposed in [6]. HE is a technique for improving image contrast, but its effect is too severe for many output images. However, different results can be obtained with minor modifications. The paper gives a concise description of adaptive HE. A key feature of this technique is the cumulating function, which is used to generate a grey level mapping from the local histogram. By choosing many alternative forms of cumulating function, one can achieve a wide variety of effects. A specific form is proposed. Through the dissimilarity of one or two parameters, the resulting process can produce a range of degrees of contrast enhancement leaving the image unchanged.

Reference [7] uses an automated technique for dehazing that requires only a single input image. This work is based on two basic observations: Clear-day images have more contrast than images plagued by bad weather. Airlight whose variation mainly depends on the distance of objects to the viewer tends to be smooth. Based on these two observations, a cost function is developed using Markov random fields, which can be optimized efficiently by various techniques, such as belief propagation or graph-cuts. This technique does not require the geometrical information of the input image, and can be used for dehazing both color and gray images. The work does not intend to fully recover the scene's original colors or albedo and is time consuming. The main goal is to solely enhance the

contrast of an input image so that the image visibility is improved. But, this approach does not fully recover the scene's original colors. The work only enhances the contrast of an input image so that the image visibility is not that improved.

A novel algorithm for visibility restoration from a single image is proposed in [8]. This visibility restoration technique consists of different steps. First, white balance is done by biasing the average of brightest colors in the image towards pure white color. Then, the atmospheric veil inference is computed by using the depth map and intensity of sky. Next, corner preserving smoothing is done using a median filter. As a next step, the image is restored by re-arranging the equation of atmospheric scattering model. Finally, tone mapping is done to get a finely toned output image. The main advantage of this technique compared with the other techniques is its speed: its complexity is a linear function of the number of image pixels only. Another advantage is the possibility to handle both color images and gray level images. But sometimes the images produced are over-saturated.

A simple and effective prior called dark channel prior (DCP) to remove haze from a single image is proposed in [9]. The dark channel prior is a type of statistics of the outdoor haze-free images. The prior states that most of the non-sky patches in haze-free outdoor images contain some pixels, which have zero or very low intensities, in atleast one color channel. Using this prior with the atmospheric scattering model, the thickness of the haze is estimated and a high quality haze-free image is recovered. This work also uses a method called Soft matting for refining the transmission map. Moreover, a high quality depth map can also be obtained as a by-product of haze removal. But the method cannot well handle the sky images. This method is also invalid when scene object is similar to airlight like snowy ground, car head lights, etc.

Reference [10] introduces an improved single image dehazing algorithm based on the atmospheric scattering physics-based models. The local dark channel prior is applied on selected region to estimate the atmospheric light, and a more accurate result is obtained. Experiments on real images validate this approach. This technique provides an accurate estimation of air light. The sky regions in the output image become brighter and smoother. This approach also requires less computation time, which is an advantage. But halo effects are produced in some regions of the output image.

A fast haze removal method from single image is discussed in [11]. The basic idea is to derive an accurate atmosphere veil that is smoother. First, an initial atmosphere scattering light is obtained through median filtering. Then it is refined by guided joint bilateral filtering to generate a new atmosphere veil which removes the abundant texture information and recovers the depth edge information. Finally, the scene radiance is recovered using the atmosphere scattering model. This technique gives better dehazed results when scene objects are distant and in places where depth changes abruptly. The technique is also fast, with linear complexity proportional to the number of pixels of the input image. But when the color of scene objects is similar to the atmospheric light, the output becomes sharp after haze removal.

A method of single image haze removal using content-

adaptive dark channel and post enhancement is introduced in [12]. In order to obtain the dark channel efficiently, an associative filter, which can transfer the structures and the gray levels of two input images to the filtering output, is proposed. A dark channel confidence is also introduced to restrict the dark channel according to the content of the image. Finally, inspired by the characteristics of the restored haze-free images, a post enhancement method is used to map the luminance with the local contrast preserved. This technique yields satisfactory results on varied hazy images. But the dehazing results are not always desirable in non-homogenous conditions.

Reference [13] proposes an effective and robust algorithm for image dehazing, which overcomes the limitations of dehazing using dark channel prior, proposed in [9]. This work takes into account the inhomogeneous atmosphere and proposes a new model for the attenuation coefficient in the inhomogeneous atmosphere, which differs from the constant attenuation coefficient generally assumed in homogeneous atmosphere. In order to get a valid transmission, a simple but effective approach to roughly detect the sky regions is proposed, by using the dark channel images of the original hazy images. With the estimated sky region, the refined transmission is adjusted. The adjusted transmission describes the optical model in inhomogeneous atmosphere more accurately. Therefore, the color distortions in sky regions have decreased, and the image contrast is highly enhanced.

A color attenuation prior for removing haze from a single image is discussed in [14]. By creating a linear model for the scene depth of the hazy image using this prior, and learning the parameters of the model with a supervised learning method, the depth information can be recovered effectively. Then the transmission map and the airlight coefficient can be easily estimated and finally, the scene radiance is restored via the atmospheric scattering model. The haze can thus be effectively removed from a single image. The work provides better efficiency and dehazing compared to previous methods and the obtained output image doesn't suffer from over enhancement. The white objects in hazy images are not treated as haze, which is another advantage. But the algorithm used in this paper is based on constant β (scattering coefficient) assumption.

A simple but effective image prior called change of detail (CoD) prior to remove haze from a single input image is used in [15]. CoD is based on two basic assumptions: First, an image object is blurred more severely in a region where haze is thicker. Second, if we sharpen and smooth a blurred image separately, the intensity difference between them in a local patch should be negatively correlated to the blurring strength. By adopting the CoD prior, the thickness of the haze can be estimated effectively to recover a high quality, haze-free image. This technique is able to handle both color and gray scale images. The technique achieved better results quickly. But, since the CoD prior is closely related to the blurring effect in hazy images, it may fail when the blur is caused by other reasons such as out of focus. Moreover, the constant airlight assumption may be unsuitable when there are multiple light sources in the scene.

Reference [16] discusses a method for estimating the optical transmission from a single hazy image. Based on this estimation, the scattered light is eliminated to increase scene visibility and recover haze-free scene contrasts. In this approach, a refined image formation model is formulated that accounts for surface shading in addition to the transmission function. This helps to resolve ambiguities in the data by searching for a solution in which the resulting shading and transmission functions are locally statistically uncorrelated. The experimental results demonstrate that this technique has an ability to remove the haze layer as well as provide a reliable transmission estimate. But this technique cannot be used for gray scale image dehazing.

A hybrid strategy based on IDCP using Guided Filter and Anisotropic Diffusion method is used in [17]. The former strategy is used for estimating and refining transmission map while the later strategy is used to estimate and refine airlight. The authors also compare the above mentioned techniques using several performance metrics such as Normalized Color difference (NCD), Color Naturalness Index (CNI) and number of saturated pixel. The results show that the visual quality of the hybrid approach is much better and the performance metrics mentioned above optimizes to a great extent.

An approach to dehaze a single input image using its semi inverse is introduced in [18]. By applying a single per pixel operation on the original image, a semi-inverse of the image is produced. Based on the hue disparity between the original image and its semi-inverse, hazy regions are identified on a per pixel basis. This helps in simple estimation of the airlight constant and the transmission map. This technique is straightforward and performs faster than existing strategies. This technique yields comparative and even better results with very low processing time. Unfortunately, this technique does not have any edge preserving property.

Reference [19] uses an efficient regularization technique to remove hazes from a single image. This technique benefits much from an exploration on the inherent boundary constraint on the transmission function. This constraint is then combined with a weighted L1-norm based contextual regularization and is modelled into an optimization problem to estimate the unknown scene transmission. An algorithm based on variable splitting is also presented to solve the problem. The technique requires only a few general assumptions and can restore a high quality haze-free image with faithful colors and fine image details. But this technique suffers from the problem of ambiguity between white objects and haze.

An efficient method to remove haze from a single input image using Fast Fourier Transform is discussed in [20]. The work focuses on an approach based on Fourier Transform to find the transmission map. The atmospheric light is estimated using the dark channel prior. Transmission map is refined by the dark channel prior method and Fast Fourier Transform. Finally, the scene radiance is recovered using the visibility restoration model. This technique can effectively remove the bad weather condition and enhance the contrast of the input images. Moreover, this approach can significantly reduce the computational complexity. The use of Fourier Transform makes this approach faster. The main advantage of this technique is that it is suitable for images with too much of sky

background.

A method to dehaze a single image using an improved atmospheric scattering model is introduced in [21]. The input image is partitioned into several scenes based on the haze thickness. Next, a rough scene luminance map is calculated by using averaging and erosion operations. Then rough scene transmission map is obtained by maximizing the local contrast and by using a way to remove the haze using an adaptive method for adjusting scene transmission based on scene features. In addition, a guided total variation model is proposed for edge optimization in order to eliminate the negative effects from the wrong scene segmentation results. This technique is effective in solving problems, including uneven illuminance, over enhanced and over saturated images. But for low PSNR values, the image smoothing is poor and complex iterative steps are used in edge optimization.

IV. CONCLUSION

Haze removal techniques are widely used for many image processing and computer vision applications. It is found that most of the existing researches in this area have neglected some issues. i.e, no single approach can be proved efficient for dehazing in every different circumstance. The survey has shown that the presented methods have neglected the techniques to reduce the noise which is present in the output images of the existing haze removal algorithms. The problem of uneven and over illumination is also an issue for dehazing methods.

Even though the existing haze removal methods were able to remove haze effectively from the input images in their own ways, there still arise some challenges in the area of haze removal. Most of the state-of-the art techniques of haze removal are having high time and space complexity. The practical computer vision and image processing systems usually needs the processing to be done in a relatively small amount of time. An ideal haze removal method should dehaze the images in a relatively small amount of time. The complexity can be reduced by using simple and efficient algorithms with less memory and hardware requirements. The adaptiveness of haze removal methods should also be improved. Most of the practical computer vision systems need the images to be processed automatically and adaptively. An ideal haze removal method with a proper design can solve the issue of adaptiveness. The quality of haze removal methods is another factor to be given importance. The problem of noise and distortion remain unresolved in the processing of the images with dense haze. An ideal haze removal method should be able to preserve all the fine details of the image and make it completely free of noise, haze and other distortions by incorporating some sort of noise removal methods also so as to preserve the minute details. Finally, it would be better to introduce an objective quality assessment tool in order to assess the quality of haze removal algorithms, so that the researchers no longer need to compare their output with others' works. Instead they can check the quality using the assessment tool.

V. REFERENCES

- [1] E. J. McCartney, Optics of the Atmosphere: Scattering by Molecules and Particles. New York, NY, USA: Wiley, 1976.
- [2] S. G. Narasimhan and S. K. Nayar, "Vision and the atmosphere", International Journal of Computer Vision, 48(3), 233-254, 2000.
- [3] S. G. Narasimhan and S. K. Nayar, "Interactive (de) weathering of an image using physical models," in Proc. IEEE Workshop Color Photometric Methods Comput. Vis., vol. 6. France, 2003, p. 1.
- [4] Y. Y. Schechner, S. G. Narasimhan, and S. K. Nayar, "Polarization-based vision through haze," Appl. Opt., vol. 42, no. 3, pp. 511-525, 2003.
- [5] S. Sarit Shwartz, Einav Namer and Yoav Y. Schechner, "Blind Haze Separation", Proc. IEEE Computer Vision and Pattern Recognition (CVPR), vol. II, 1984-1991, 2006.
- [6] J. Alex Stark, "Adaptive Image Contrast Enhancement Using Generalizations of Histogram Equalization," IEEE Trans. Image Processing, Vol. 9, No. 5, pp. 889-896, May 2000.
- [7] R. T. Tan, "Visibility in bad weather from a single image", Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (CVPR), 18, 2008.
- [8] J.P. Tarel and N. Hautiere, "Fast visibility restoration from a single color or gray level image", Proc. IEEE 12th Int. Conf. Comput. Vis. (ICCV), 2201-2208, 2009.
- [9] K. He, J. Sun, and X. Tang, "Single image haze removal using dark channel prior", IEEE Trans. Pattern Anal. Mach. Intell., vol. 33, no.12, 2341-2353, 2010.
- [10] Y. Wang and Bo Wu, "Improved single image dehazing using dark channel prior", Proc. IEEE Int. Conf. on Intelligent Computing and Intelligent Systems (ICIS), 2011.
- [11] Xiao C, Gan J, "Fast image dehazing using guided joint bilateral filter", Vis. Comput., 28, 713-721, 2012.
- [12] Li B, Wang S, Zheng J, Zheng L, "Single image haze removal using content-adaptive dark channel and post enhancement", IET Comput. Vis., 8, 131-140, 2013.
- [13] Shi Z, Long J, Tang W, Zhang C, "Single image dehazing in inhomogeneous atmosphere", Optik Int. J. Light Electron Opt., 125, 3868-3875, 2014.
- [14] Q. Zhu, J. Mai, and L. Shao, "A fast single image haze removal algorithm using color attenuation prior", IEEE Trans. Image processing, 3522-3533, 2015.
- [15] Li J, Zhang H, Yuan D, Sun M, "Single image dehazing using the change of detail prior", Neurocomputing, 156, 1-11, 2015.
- [16] R. Fattal, "Single image dehazing", ACM Trans. Graph., vol. 27, no. 3, 72, 2008.
- [17] Pranjal Garg, Shailender Gupta, Bharat Bhushan and Prem Chand Vashist, "A Hybrid Defogging Technique Based On Anisotropic Diffusion And IDCP Using Guided Filter", International Journal of Signal Processing, Image Processing and Pattern Recognition, Vol. 8, No. 7, 123-140, 2015.

- [18] C. O. Ancuti, C. Ancuti, C. Hermans and P. Bekaert ,
“A fast semi inverse approach to detect and remove
the haze from a single image” , Proc. Asian Conf.
Comput. Vis.(ACCV), 501-514, 2010.
- [19] G. F. Meng, Y. Wang, J. Duan, S. Xiang and C. Pan,
“Efficient image dehazing with boundary constraint
and contextual regularization”, Proc. IEEE Int. Conf.
Comput.Vis. (ICCV), 617-624, 2013.
- [20] Apurva Kumari and S.K.Sahoo, “Real Time
Visibility Enhancement for Single Image Haze
Removal”, Proc. Int. Conf. on Information Processing
(IMCIP), 2015.
- [21] Mingye Ju , Dengyin Zhang , Xuemei Wang, “Single
Image Dehazing via an Improved Atmospheric
Scattering Model”, Vis.Comput.,113, 2016.