A Survey on Visibility Enhancement Techniques in Degraded Atmospheric Outdoor Scenes

Sourav Dey Roy* and Mrinal Kanti Bhowmik

Department of Computer Science and Engineering, Tripura University (A Central University), Tripura (W), India

souravdeyroy49@gmail.com* and mrinalkantibhowmik@tripurauniv.in

Abstract— **Often the images of outdoor scenes are drastically altered by the atmospheric particles and loses the contrast and gradient information. Accurate detection of image features from outdoor scenes requires clear visibility in computer vision applications. Currently, there has been an augmented attention in the communities of image processing towards enhancing the visibility of outdoor images acquired in specific atmospheric conditions (i.e. fog, haze, mist, etc.). The paper presents a significant methodological review on visibility enhancement techniques degraded by different weather conditions in outdoor environment. In this survey, we categorized the enhancement techniques on the basis of approaches they used to restore the visibility and provide comprehensive description of different methods in each category.**

***Index Terms*—Computer Vision; Atmospheric Conditions; Visibility Enhancement Techniques; Comprehensive Survey**

I. Introduction

Computer vision is all about visualizing and interpreting the real world around us with wide scope of applications in our daily lives such as surveillance, topography categorization, and independent navigation [1]. Although computer vision systems are being appreciated for its major success in indoor environments but still has been limited in outdoor environments [2]. There are several reasons for degradation of outdoor scenes but one of the main reason is presence of bad weather conditions. These conditions can be steady (i.e. fog, mist and haze) or dynamic (i.e. rain and snow) based on types and sizes of the particles involved and their concentrations in space [2]. As a result, the outdoor images acquired under different weather conditions loses the contrast and color fidelity. Therefore enhancing the quality of image in poor visibility conditions is an evitable task for various computer vision applications.

Numerous approaches for visibility enhancement have been proposed. On the basis of study of the most relevant works published in the past, the paper mainly explores a critical review on different categories of visibility enhancement in weather degraded outdoor scenes and provide detailed descriptions of various representative methods in each of these category. We aim to provide researchers, who require an enhancement techniques for particular application, to select the most appropriate algorithm for their certain needs and hope to provide a direction for the development of new enhancement methods.

The whole paper is organized as: Section II, elaborately describes the methodological review on the atmospheric scattering based image enhancement techniques. In Section III the review on the fusion based image enhancement techniques is described. Section IV reports different dark channel prior based image enhancement techniques. In Section V, the review on the filtering based image enhancement techniques has been illustrated. And finally, section VI concludes the paper.

II. Review on Atmospheric Scattering Model Based Visibility Enhancement Techniques

Scattering of light by turbid medium is complicated and mainly relies on the types, orientations, sizes, and distributions of particles creating the media [3]. The traditional atmospheric scattering approach focuses on two components i.e. attenuation and airlight, which form the basis of this work as proposed by S.G. Narasimhan et.al. [4] in 2002. The attenuation model defines the pattern in which the light gets attenuated as it travels from a scene point to the observer and the airlight model measures how atmosphere acts as a light source by reflecting illumination towards an observer. The analysis of various visibility enhancement techniques based on atmospheric scattering model are shown in TABLE I. In [5], Y.A. Zubaidy et.al. proposed a novel method to remove the effect of atmospheric particles from outdoor images based on two prior assumptions. First, skylight value was detected from the pixels set that have high intensity and low variance color contrast and then precise estimation of the real homogenous atmospheric veil depending on the classification of rough atmospheric veil into a number of levels that equals the number of color contrast in the input image. To meet up the specific necessities, the sets of white area are detected to estimate the skylight and then used homogenous atmospheric veil method to calculate direct attenuation. In [6], I. Enesi et.al. proposed a method for contrast enhancement based on monochrome atmospheric scattering model that illustrates the affect of scene intensities by homogeneous weather conditions and extracted iso-depth regions from the scene to restore scene contrast. In [1], R.T. Tan presents a technique to remove haze from the images based on two basic observations. The first observation is that the images with enhanced visibility have more contrast than images affected by bad weather and the second observation is that the variation of airlight mainly relies on the distance of objects to the viewer. Based on these two observations, a cost function is introduced in the framework of Markov random fields in which optimization is carried out using graph-cuts or belief propagation. In [2], S.G. Narasimhan et.al. proposed a physics based method to enhance the scene contrast from two multiple images. A monochrome atmospheric scattering model is proposed that defines the affect of scene intensities by homogeneous weather conditions. Also a simple restoration technique based on the concept of contrast stretching is derived for scenes with known depth segmentation and provides strong physical restrictions for scene structure. These restrictions are exploited to automatically identify the discontinuities in depth information and to improve entire scene structure from two images acquired in different atmospheric conditions and restored the images using the computed structure. In [7], S.G. Narasimhan presents a complete set of models, algorithms and image datasets for understanding the nature of image in bad weather. The models presented here are classified as single

978-1-5386-2175-2/17/$31.00 ©2017 IEEE

TABLE I
METHODOLOGICAL REVIEW ON DIFFERENT VISIBILITY SCATTERING MODEL BASED IMAGE ENHANCEMENT TECHNIQUES

Author/ Year	Method Used	Database/ Type of Images	Atmospheric Condition(s)	Accuracy/ Result	Observation
Y.A. Zubaidy et.al./ 2013 [5]	Skylight detection method, atmospheric veil method and scattering atmospheric model	Natural scene images	Fog and Haze	Subjective evaluation is done	The proposed method recover scene albedo by utilizing various assumptions about airlight or scene colors.
I. Enesi et.al./ 2012 [6]	Monochrome atmospheric scattering and depth segmentation	Synthetic and Real world images of road scenes, trees, buildings	Fog, Haze, Mist and Rain	Subjective evaluation is done	The proposed method can be applied on video sequences and describe a simple heuristic for contrast enhancement of the scene whose depths are unknown.
R. T. Tan/ 2008 [1]	Markov random fields and atmospheric scattering model	Real world images of road scenes, trees, buildings	Fog and Haze	Subjective evaluation is done	Images with enhanced visibility have more contrast than images affected by bad weather
S.G. Narasimhan et.al./ 2003 [2]	Monochrome atmospheric scattering model	Images and videos of road scenes, trees, buildings	Haze, Mist and Fog	Subjective evaluation is done	The proposed algorithm does not require structure of priori scene, distributions of scene reflectance, or comprehensive information about the weather condition.
S.G. Narasimhan / 2003 [7]	Dichromatic model and the polarization model	WILD database	Fog, Haze and Mist	Subjective evaluation is done	The proposed method is effective under a wide range of weather conditions and can be applied to gray scale, RGB color, multispectral and even IR images.

scattering and multiple scattering models. Based on the contrast model, dichromatic model and the polarization model, algorithms are proposed to acquire certain scene properties, such as 3D structure from one or more images acquired in poor weather conditions. The efficient properties of the medium is estimated to remove the glows around sources obtaining a clear visibility in the image.

III. REVIEW ON FUSION BASED VISIBILITY ENHANCEMENT TECHNIQUES

The traditional fusion methods are the processes in which two or more images are combined into a single image for collecting more significant information from the original images. In general, most fusion techniques are using two or more images simultaneously obtained from multi-sensors but the use of multiple sensors may be high expensive and may not provide better results. To conquer it, several researchers established the use of a fusion-based technique for dehazing of a single image. The analysis of these papers are shown in TABLE II. In [8], J.M. Guo et.al. introduced a single-image dehazing approach based on the optical scattering model. The algorithm first estimates the atmospheric light using Gaussian-based dark channel technique by attaining the color information. In the next part, to enhance the low contrast part in the sky region, an improved contrast limited adaptive histogram equalization (CLAHE) is introduced. Then the transparency function is precisely estimated using the fusion weighting function. Consequently, the hazy image is restored based on traditional optical model described in the previous section. In [9], C.O. Ancuti et. al. proposed a fusion-based approach to restore the visibility of degraded images based on white balance and a contrast enhancing procedure. The main notion behind this technique is that they have derived two input images from the original image. Moreover, the fusion based enhancement technique for each pixel approximates the perceptual based qualities (called weight maps) by three normalized weight maps (luminance, chromatic and saliency). In [10], J. Li et.al. proposed an image restoration method in which atmospheric scattering model is used to produce a sequence of virtual images which are transformed and produced the wavelet tower of these virtual image. Then each layer is processed with the order from low frequency to high frequency. Two different fusion rules i.e. region based low and high frequency fusion rules are applied on different layer to generate the wavelet coefficients and applied inverse transform onto the wavelet coefficients after fusion to reconstruct the images. In [11], H. Zhang et.al. proposed a wavelet fusion based novel restoration method. In this method, histogram equalization is used as a pre-processing, then wavelet transform is used to decompose the image and non-linear operator is used to enhance high-frequency part of the decomposition image.

IV. REVIEW ON DARK CHANNEL PRIOR BASED VISIBILITY ENHANCEMENT TECHNIQUES

The Dark Channel Prior (DCP) is based on the statistics that in most of the non sky regions, there are certain pixels (dark pixels) that have very low intensity in at least one of its RGB color channel and can provide efficient information of the haze's transmission. The DCP was first proposed by K. He et.al. [12] to estimate the depth information in hazy image, and then later make use of this concept to regain the scene albedo. After the concept of DCP was proposed, the approach for image enhancement by means of DCP framework developed rapidly. The analysis of these papers are shown in TABLE III. In [13], Md.A. Imtiyaz et.al. proposed a technique

TABLE II
METHODOLOGICAL REVIEW ON DIFFERENT FUSION BASED VISIBILITY ENHANCEMENT TECHNIQUES

Author/ Year	Method Used	Database/ Type of Images	Atmospheric Condition (s)	Accuracy/ Result	Observation
J.M. Guo et.al./ 2017 [8]	Optical based defogging techniques and contrast limited adaptive histogram equalization (CLAHE)	Real world images of roads, buildings and trees	Fog	Weighted-Mean Square Error): IW-MSE: <100 Execution time: 0.393 seconds	The proposed method has the capability to reduce the gleaming effects mostly noticed in the enhanced images.
C.O. Ancuti et. al./ 2014 [9]	White balance using Grey World and Contrast Enhancing using gamma correction	Real world images of car, building and trees	Fog, Haze, Smoke and Dust	Rate of new visible edges (e): 0.09 Mean ratio (σ): 0.01 Percentage of pixels (r): 1.42	The method does not need any information regarding the scene depth and eliminate complex atmospheric scattering model.
J. Li et.al./ 2010 [10]	Physics -based model, Wavelet fusion technique	Natural Scene Images	Haze and Fog	Standard deviation: 85.455 Average gradient: 2.579 Spatial frequency: 9.410	The proposed method can overcome the limitations regarding the concept of multi-images or multi-sensors fusion.
H. Zhang et.al./ 2010 [11]	Wavelet transform, histogram equalization and non-linear operator	Real world images of roads, buildings and trees	Fog	Not Provided	The proposed method enhance the texture information and edge details in the images.

TABLE III
METHODOLOGICAL REVIEW ON DIFFERENT DARK CHANNEL PRIOR (DCP) BASED VISIBILITY ENHANCEMENT TECHNIQUES

Author/ Year	Method Used	Database/ Type of Images	Atmospheric Condition(s)	Accuracy/ Result	Observation
Md.I. Anwar et.al./ 2017 [13]	DCP followed by Weighted Least Square and High Dynamic Range	'ny17', 'y01', 'y16', 'canon7', 'cityscape', 'K-080-000005', 'road'	Fog	Color Information Entropy (CIE): 7.3860 Colorfulness Index (CI): 24.68 Contrast Gain (CG): 0.1035	The proposed method preserves the detailed clear edges color quality for RGB images and other image transformation models.
S. Jadhav et.al./ 2016 [14]	DCP model and ACCLAHE with gamma transformation	Real world images of road scenes, trees, buildings	Fog	Contrast Gain (CG): 5.308 Entropy: 0.1904 Execution time: 8.687 seconds	The use of gamma transformation in the proposed method, refine the transmission map for visibility enhancement of an image.
J. Li et.al./ 2015 [15]	An effective change of detail (CoD) prior, was used to remove haze from a single image.	Real world images of road scenes, trees, buildings	Fog and Haze	Rate of new visible edges (e): 0.1737 Mean ratio (σ): 0.0096 Percentage of pixels (r): 1.5422	The CoD has the capability to process a wide variety of images, which do not contain enough color information and acquired within a thin spectral band.
J.B. Wang et.al./ 2015 [16]	Atmospheric scattering model and dark channel prior	Real world images of road scenes, trees, buildings	Fog and Haze	Mean Square Error (MSE): 46.1194 Peak Signal to Noise Ratio (PSNR):34.2006 Average Gradient (AveGrad): 0.0109	The proposed method obtains noticeable results, and the dehazing of scenario details are obtained for processing non-sky area images.
J. Chen et.al./ 2013 [17]	window-variant dark channel prior	Real world images of road scenes, trees, buildings	Fog and Haze	Not Provided	The proposed method improved the limitations of the traditional dark channel prior and creates accurate depth estimation in the scenes.

for restoration of fog degraded images. The proposed method uses the concept of DCP principle followed by High Dynamic Range (HDR) tone mapping using Weighted Least Squares (WLS) for contrast adjustment. HDR images provides the light values acquired for the scene while the ringing effect is reduced by WLS edge preserving filter which computes detail layers and recombines them with strong fine details. In [14], S. Jadhav et.al. presented a fog removal method by applying DCP model and Adaptively clipped contrast limited adaptive histogram equalization (ACCLAHE) with gamma transformation. In the preliminary step, the input image is converted into a double value for dark channel (DC) and produced DC foggy image with zeros. After that atmospheric light is estimated using minimum filter and transmission map is calculated for visibility of an image. Then refinement of the transmission map is carried out using for using gamma transformation and applied ACCLAHE enhancement method for protecting the image edges. In [15], J. Li et.al. proposed a novel dehazing method i.e. change of detail (CoD) method to determine the thickness of the haze. The CoD is generally based on the local information as compared to the DCP technique in which the color information plays a fundamental role. In [16], J.B. Wang et.al. proposed a hybrid method by combining the atmospheric scattering model and DCP principle [12] for enhancement of haze degraded images. First, the transmission map is improved and second the method conquer the lack of the DCP and reduces the negative impact of white objects or sky areas on the entire image and obtain a clear visibility. In [17] J. Chen et.al. used DCP to approximate the information of scene depth using single image but the prior fails for pixels with low color saturation. On the basis of this remark, the region in which there is random change in color belonging to the similar depth information, a window variation mechanism is proposed based on the complexity of neighbourhood scenes and saturation rate to achieve an supreme cooperation between depth resolution and precision.

V. REVIEW ON FILTERING BASED VISIBILITY ENHANCEMENT TECHNIQUES

In image processing, filtering is a neighbourhood based approach, in which each pixel in the output image is represented by applying some algorithm to the neighbouhood pixels of the corresponding input pixels so as to overwhelm either the high or the low frequencies. Some filtering based enhancement algorithms have been proposed to address the problem successfully by various researchers. The analysis of these papers are shown in TABLE IV. In [18], H. Geethu et.al. proposed a weighted guided image filter (WGIF) by integrating edge-aware weighting in guided image filter (GIF) for smoothening. The weighting coefficients are calculated using box filter for all the pixels the guidance image. The normalized weighting is then take on to acquire the WGIF. In the next step, an efficient fog removal algorithm is proposed in which bilateral filter is used to generate the air light. In [19], M. Negru et.al. proposed an fog removal algorithm in which atmospheric veil is considered as an input to the system that consists of minimum in different RGB color channels independently. After that a median filter with a variable size and exponential filter is applied on the whole atmospheric veil and enhanced the fog degraded image. In [20], Apurva et al. proposed a method for restoration of fog degraded images in which the DCP [12] is used for estimation of transmission map and then post- processing using gamma transformation is carried out to attain the actual relative luminance and finally refined based on median. In [21], K.B. Gibson et.al. proposed a technique in which the scene depth information is estimated using dark channel prior [12] that contains significant noise and needs refinement. The speed of the method is achieved by using separable filters that approximate the Wiener filter for refining the estimation of scene depth information. In [22], Z. Xing et.al. proposed a traditional Retinex-based enhancement methods that can encounter the occurrence of halo artifacts in high dynamic range images. The proposed method firstly convert the RGB images to HSI images, then the brightness information present in the images are converted into frequency domain by Fourier transform. Then low frequency components are eliminated using high pass filter and again reconvert back to spatial domain using inverse Fourier transform and synthesize finally using histogram equalization.

After an extensive survey, it is found that the visibility restoration based on multiple image approaches (i.e. atmospheric scattering model based techniques) requires some additional information such as elevation, camera position and the approximate distance between the view point and the sky

TABLE IV
METHODOLOGICAL REVIEW ON DIFFERENT FILTERING BASED VISIBILITY ENHANCEMENT TECHNIQUES

Author/ Year	METHOD USED	Database/ Type of Images	Atmospheric Condition(s)	Accuracy/ Result	Observation
H. Geethu et.al./ 2016 [18]	Weighted Guided Image Filter (WGIF)	Natural Scene Images	Fog and Haze	Subjective Evaluation is done	The proposed algorithm does not need subjective intervention and does not take into account the thickness of the fog.
M. Negru et.al./ 2015 [19]	Median filter, Exponential Filtering Restoration Method	FRIDA Dataset, Real world images of car, building and trees	Fog	Rate of new visible edges (e): 0.0653 Mean ratio (σ): 0.0006	The proposed method provides better results for restoration of homogenous and heterogeneous foggy images.
A. Kumari et.al./ 2014 [20]	Median Filtering and Gamma Transformation	Natural Scene Images	Fog	Contrast gain: 0.0427 Processing time: 1.23 seconds Percentage of saturated pixels: 0.0002	The proposed method relatively performs better enhancement as compared to bilateral filtering method.
K.B. Gibson et.al./ 2013 [21]	Adaptive Wiener Filter	Natural Scene Images and synthetic images	Fog and Haze	Subjective Evaluation is done	The proposed method usually takes less computation time because of the simplicity of the algorithm which uses the linear filter to approximate the local statistics.
Z. Xing et.al./ 2011 [22]	Fourier transform, High pass filtering and Histogram equalization	Real world images of road scenes, trees, buildings	Fog	Not Provided	The proposed method can eliminate halo artifacts and color distortion and has less processing time.

area of the captured images. Unfortunately, these methods usually require additional expensive hardware devices in order to achieve efficiently and hence time consuming and is difficult to apply in real time applications. On the otherhand, recently most of studies started focuses on single-image approaches (i.e. fusion based and DCP based techniques) to restore the visibility of the weather degraded scenes. The main advantage of these methods is that these methods usually do not need any information about scene depth and also avoid complex atmospheric scattering model.

VI. CONCLUSION

Enhancement of outdoor images degraded by different bad weathers has been an increased interest in the last decades. In this paper, the methodological review of different visibility enhancement approaches and contribution of research communities in each of these category is described elaborately. Studies so far indicate that, the critical review can be a valuable contribution to develop novel algorithms for visibility enhancement and comparison of this method with the state of art in future.

ACKNOWLEDGMENT

The work presented here is being conducted under the research project Grant No. SMR/PD(R)/NER/2012-13/Thermography, Dated: 22/03/2011 from SAMEER, Government of India.

REFERENCES

[1] R.T. Tan, "Visibility in bad weather from a single image," IEEE Conference on Computer Vision and Pattern Recognition (CVPR 2008), IEEE, pp: 1-8, 2008.

[2] S.G. Narasimhan and S.K. Nayar, "Contrast restoration of weather degraded images," IEEE transactions on pattern analysis and machine intelligence, Vol. 256, pp. 713-724, 2003.

[3] R.C. Henry, S. Mahadev, S. Urquijo and D. Chitwood, "Color perception through atmospheric haze," JOSA A 17.5, pp. 831-835, 2000.

[4] S.G. Narasimhan and S.K. Nayar, "Vision and the atmosphere," International Journal of Computer Vision, Vol. 48, No. 3, pp. 233-254, 2002.

[5] Y.A. Zubaidy and R.A. Salam, "Removal of atmospheric particles in poor visibility outdoor images," Indonesian Journal of Electrical Engineering and Computer Science, Vol. 11, No. 8, pp. 4244-4250, 2013.

[6] I. Enesi and R. Miho, "A Fast Algorithm for Contrast Restoration of Weather Degraded Images," 2012 Sixth International Conference on Complex, Intelligent and Software Intensive Systems (CISIS), IEEE, pp. 636-641, 2012.

[7] S.G Narasimhan, "Models and algorithms for vision through the atmosphere," Diss. Columbia University, 2003.

[8] J.M. Guo, J.Y. Syue, V. Radzicki and H. Lee, "An Efficient Fusion-Based Defogging," IEEE Transactions on Image Processing, Vol. 26, No. 9, pp. 4217 - 4228, 2017.

[9] C.O. Ancuti and C. Ancuti, "Single image dehazing by multi-scale fusion," IEEE Transactions on Image Processing, Vol. 22, No. 8, pp. 3271-3282, 2013.

[10] J. Li, Y. Wang, H. Sun, R. Tian and Y. Zhang, "Restoration of an atmospherically blurred image based on physical model fusion approach," IEEE 10th International Conference on Signal Processing (ICSP), IEEE, pp. 801-804, 2010.

[11] H. Zhang and Y. Qing, "Fog-degraded image clearness based on wavelet fusion," 2010 International Conference on Intelligent System Design and Engineering Application (ISDEA), Vol. 1, IEEE, pp. 759-761, 2010.

[12] K. He, J. Sun, and X. Tang, "Single image haze removal using dark channel prior," IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 33, No. 12, pp. 2341-2353, 2011.

[13] Md.A. Imtiyaz, and Arun Khosla, "Vision enhancement through single image fog removal," An International Journal of Engineering Science and Technology, Elsevier, Vol. 20, No. 3, pp. 1075-1083, 2017.

[14] S. Jadhav, J.S. Kumare, R.K. Singh, "An Innovative Fog Removal and Enhancement using DCP and ACCLAHE with Gamma Tranformation", International Journal of Advanced Research in Computer Science and Software Engineering, Vol. 6, No. 6, pp. 661-669, 2016.

[15] J. Li, H. Zhang, H., D. Yuan and M. Sun, "Single image dehazing using the change of detail prior," Journal of Neurocomputing, Vol. 156, Elsevier, pp. 1-11, 2015.

[16] J. Li, H. Zhang, D. Yuan, and M. Sun, "Single image dehazing with a physical model and dark channel prior," Journal of Neurocomputing, Vol. 149, Elsevier, pp. 718-728, 2015.

[17] J. Chen and L.P. Chau, "An enhanced window-variant dark channel prior for depth estimation using single foggy image," 20th IEEE International Conference on Image Processing (ICIP), IEEE, pp. 3508-3512, 2013.

[18] H. Geethu, S. Shamna and J.J. Kizhakkethottam, " Weighted Guided Image Filtering and Haze Removal in Single Image," Procedia Technology, Elsevier, Vol. 24, pp. 1475-1482, 2016.

[19] M. Negru, S.N. Mihai and R.I. Peter, "Exponential Contrast Restoration in Fog Conditions for Driving Assistance," IEEE Transactions on Intelligent Transportation Systems, Vol. 16, No. 4, pp. 2257-2268, 2015.

[20] A. Kumari, J. Thomas and S. K. Sahoo, "Single image fog removal using gamma transformation and median filtering," 2014 Annual IEEE India Conference (INDICON), IEEE, pp. 1-5, 2014.

[21] K.B. Gibson and T.Q. Nguyen, "Fast single image fog removal using the adaptive wiener filter," 20th IEEE International Conference on Image Processing (ICIP), IEEE, pp. 714-718, 2013.

[22] Z. Xing, L. Yu, T. Xiaoling and L. Huilong, "A Fog-removing Method of Colorized Images Based on HighPass Filtering," Fourth International Symposium on Computational Intelligence and Design (ISCID),Vol. 2, IEEE, pp. 99-102, 2011.