Qualitative Evaluation of Visibility Enhancement Techniques on SAMEER-TU Database for Security and Surveillance

Sourav Dey Roy, Mrinal Kanti Bhowmik and Siddhartha Shankar Saha

Department of Computer Science and Engineering, Tripura University (A Central University), Suryamaninagar-799022, Tripura (W), India

souravdeyroy49@gmail.com,mkb_cse@yahoo.co.in and siddhartha.agt90@gmail.com

Abstract—**Computer vision applications such as surveillance, topography categorization, and independent navigation need accurate detection of image features and hence requires clear visibility. But the images captured in outdoor scenes are usually degraded by the particles in the atmosphere and hence loses the contrast and color fidelity. The paper presents a significant methodological review on different categories of visibility enhancement techniques in weather degraded outdoor scenes and provides comprehensive descriptions of various representative methods in each of this category. Based on the rigorous review of these publications, the paper also explores a comparative analysis of some prominent image enhancement techniques for visibility restoration in our own SAMEER-TU database to verify the robustness of these used methods.**

***Index Terms*—Computer Vision; Atmospheric Conditions; Visibility Enhancement; Quality Assessment; Comparative Analysis**

I. INTRODUCTION

For the last few decades, imaging technology has the potential to provide great benefits in computer vision applications. It is an interdisciplinary research program with broad range of applications that can impact our everyday lives such as surveillance, traffic monitoring, augmented reality, vehicle navigation, etc. Although computer vision systems are being appreciated for itsmajor success in indoor environments but still has been limited in outdoor environments [1]. Analyzing the aspects of outdoor images under subjective lighting and weather conditions is a general difficulty in computer vision and generally relies on various weather conditions. These conditions can be classified into 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]. A great deal of effort has been done into for measuring the physical properties of various atmospheric conditions.

Due to bad weather conditions, contrast of the scene gets degraded affecting the visibility of the scene. It occurs when the light beams travel from a scene point to the camera through the atmosphere and the light intensity gets attenuated by the atmospheric particles. Most automatic systems for monitoring, intelligent vehicles, outdoor object recognition, assume that the input images have clear visibility but unfortunately, this does not happen all the time [3]. Therefore enhancing the image quality in poor visibility conditions is an evitable task for various computer vision applications.

The paper presents a critical 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. Based on the study of the most relevant works published in the past, the paper mainly explores a qualitative analysis of some well-known image enhancement methods to restore the visibility of the image in outdoor scenes. In our study, we have used our own dataset i.e. SAMEER-TU database. The database is created through establishment of Thermography Facility Laboratory in Computer Science and Engineering Department of Tripura University (A Central University).

The whole paper is organized as; Section II describes the methodological review on different image enhancement techniques. In Section III, the designing issues and creation of SAMEER-TU database has been described elaborately. Section IV, explains the implementation of some well-known image enhancement techniques used for comparative analysis on our dataset. In Section V, performance evaluation measures have been illustrated. Section VI, reports the experimental results and comparative analysis of these enhancement techniques in SAMEER-TU database. And finally, Section VII concludes the paper.

II. REVIEW ON STATE-OF-ART METHODS FOR IMAGE ENHANCEMENT

Scattering of light by turbid medium has been one of the major research topics in the domain of atmospheric optics and astronomy communities. Generally, the actual behaviour of scattering is complicated and mainly relies on the types, orientations, sizes, and distributions of particles creating the media [4]. It has been observed that in extreme weather condition, the light passing through the atmosphere gets attenuated due to absorption and scattering and only a fraction of the reflected light reaches the observer which reduces the visibility in the image. Currently, there has been an augmented attention in the communities of image processing on various issues related to imaging under bad weather. Numerous computer aided visibility enhancement techniques have been proposed in the literature for restoration of weather degraded images. They primarily differ from each other based on the way they approach to enhance the images. The proposed task of these enhancement techniques is to recover the actual appearance from its hazy appearance. On the basis of approaches, the research communities have used to enhance the images, the whole review is divided into four categories:

- Atmospheric Scattering Model Based Image Enhancement
- Fusion Based Image Enhancement
- Dark Channel Based Image Enhancement
- Filtering Based Image Enhancement

Several researchers promote the application of these four approaches as a basic framework to develop algorithms for visibility restoration in outdoor scenes. The brief summary of

TABLE I
METHODOLOGICAL REVIEW ON DIFFERENT IMAGE ENHANCEMENT TECHNIQUES IN OUTDOOR WEATHER DEGRADED SCENES

Approach	Author/ Year	Method Used	Database/ Type of Images	Atmospheric Condition (s)	Accuracy/ Result
Atmospheric Scattering Model Based Image Enhancement Techniques	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
	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
	R. T. Tan/ 2008 [3]	Markov random fields and atmospheric scattering model	Real world images of road scenes, trees, buildings	Fog and Haze	Subjective evaluation
	S.G. Narasimhan et.al./ 2003 [1]	Monochrome atmospheric scattering model	Images and videos of road scenes, trees, buildings	Haze, Mist and Fog	Subjective evaluation
	S.G. Narasimhan / 2003 [7]	Dichromatic model and the polarization model	WILD database	Fog, Haze and Mist	Subjective evaluation
Fusion Based Image Enhancement Techniques	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
	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
	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
Dark Channel Prior Based Image Enhancement Techniques	J. Li et.al./ 2015 [13]	An effective image prior, change of detail (CoD) prior, was used to remove haze from a single input 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
	J.B. Wang et.al./ 2015 [14]	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: 0.0109
	J. Chen et.al./ 2013 [15]	Window-variant dark channel prior	Real world images of road scenes, trees, buildings	Fog and Haze	Not Provided
	H. Xu et.al./ 2012 [16]	Dark channel prior with bilateral filter	Real world images of road scenes, trees, buildings	Fog and Haze	Subjective evaluation is done and execution time is 0.39s
	Y. Wang et.al./ 2010 [18]	Atmospheric scattering physics based model and dark channel prior	Real world images of road scenes, trees, buildings	Fog and Haze	Subjective evaluation
Filtering Based Image Enhancement Techniques	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
	A. Kumari et.al./ 2014 [20]	Gamma Transformation and Median Filtering	Natural Scene Images	Fog	Contrast gain: 0.0427 Percentage of saturated pixels: 0.0002
	K.B. Gibson et.al./ 2013 [21]	Adaptive Wiener Filter	Natural Scene Images and synthetic images	Fog and Haze	Subjective Evaluation is done
	A. K. Tripathi et.al./ 2012 [22]	Histogram equalization, Bilateral filtering, Histogram stretching	‘pumpkins’, 'lonavala01’, ‘lonavala02’, 'ny17’, ‘y01’, ‘y16’	Fog	Contrast Gain: 5.0444 Percentage of saturated pixels: 0.0001
	Z. Xing et.al./ 2011 [23]	Fourier transform, High pass filtering and Histogram equalization	Real world images of road scenes, trees, buildings	Fog	Not Provided
	Z. Hongkun et.al./ 2011 [24]	Improved mean shift filtering	Real world images of road scenes, trees, buildings	Fog	Subjective Evaluation

all the techniques proposed by different authors in their research work is listed in TABLE I.

After an extensive survey, it is found that the image enhancement methods as proposed by Ancuti et.al. (Fusion based strategy) [9], Tarel et.al. (Filtering based strategy)[25], He et.al. (Dark channel strategy) [12], Li et.al. (Structure-Texture decomposition based strategy) [26], Nishino et.al. (Bayesian probabilistic strategy) [27], Meng et.al. (Boundary constraint based strategy) [28] and Bhattacharya et.al. (Stochastic enhancement strategy) [29] are most simple, effective well known techniques and used by most researchers as standard techniques for their study. So in our work we have used these seven enhancement methods for comparative study.

III. DESIGNING OF SAMEER-TU DATABASE

Generally the appearance of scene alters depending on several factors such as geometrical view, scene construction, illumination and weather conditions. Research communities have sparked off thunder for creation of image databases under controlled indoor environments [30-33]. However this database does not contain the complete variability of appearance due to illumination and weather conditions in

TABLE II
DISTRIBUTION OF NATURAL SCENE IMAGES IN SAMEER-TU DATABASE

Distribution of SAMEER-TU Outdoor Database (i.e. Natural Scene Images) in Uncontrolled Conditions						
Image Type	Camera Model	Number of Scenes	Capturing Condition			Total Images
			Foggy Condition	Poor Illumination Condition	Normal Condition	
Visual	FLIR E60	12	40	28	52	120
Thermal		12	40	28	52	120
Visual	Nikon D5100	12	1020	250	4370	5640
Total Number of Images			1100	306	4474	5880

outdoor environment. The SAMEER-TU Database [34] is designed through establishment of Thermography Facility Laboratory in Computer Science & Engineering Department of Tripura University (A Central University) under a research project with grant from the Society of Applied Microwave Electronics Engineering & Research (SAMEER), R & D Lab of Ministry of Electronics & Information Technology (MeitY), Government of India. In this database, 5880 Natural Scene Images and 1770 Face Images are captured in outdoor conditions; 280 face images in controlled condition; 5 thermal videos of 50 mins time duration and 10 visual videos of 179 min 50 sec in uncontrolled condition. As the paper mainly emphases on visibility enhancement techniques for refining the contrast of weather degraded images. So only the degraded images due to the presence of fog and its corresponding clear have been used from this database to experiment the enhancement algorithms in terms of qualitative assessment. The image acquisition setup and overall statistics of the natural scene images of this database are described below:

A. Environmental Condition and Camera Setup for Data Acquisition

The SAMEER-TU Database are captured from different locations of Tripura likely to be Tripura University Campus, India-Bangladesh International Border and different crossings of Agartala city. The captured scene are urban scene with buildings, trees and sky with range from about 100 meters to about 5 kilometer so as to facilitate the observation of weather effects on scene appearances. All these natural scene images are captured in an outdoor environment in foggy and normal conditions. The several factors which are considered during data acquisition was shown in Fig.1 to reduce the negative influence of analysis.

B. Distribution of Natural Scenes Images in the dataset

The natural scene images of SAMEER-TU database consists of 5640 visual images captured by Nikon D5100 and 120 images of visual and its corresponding thermal images captured by FLIR E60. This dataset contains a widespread range of images under illumination and weather conditions (especially in foggy condition). The overall distribution of natural scene images is shown in TABLE II. Images are captured after every 15 mins (i.e. 10 times in every 15 mins) from 6 AM to 6 PM in alternate 5 days in the month of January to March 2014. The spatial resolution of each image is 4928 × 3264 pixels with 24 bits per pixeland the pixel resolution is 10 bits per pixel per color channel. Each image contains the useful ground truth information such as visibility, temperature, humidity, wind speed, dew point and so on obtained per hour based on the information from Regional Meteorological Department of Tripura. On the basis of visibility parameters and other ground truth information, the weather condition is categorized as Foggy, Poor Illumination and Normal conditions. Some of the sample natural scene images of SAMEER-TU database are shown in Fig. 2.

Fig. 2 Sample Natural Scene Images of SAMEER-TU Database

IV. COMPREHENSIVE DISCUSSION OF IMAGE ENHANCEMENT TECHNIQUES

A. Fusion based strategy

The key theory of fusion-based approach [9] to restore the visibility of degraded images is that from the original hazy image, two images are producedbased on white balance and a contrast enhancing procedure. Moreover, for each pixel of the derived inputs, the desired perceptual established attributes i.e. luminance weight map, chromatic weight map and saliency weight map are calculated. Each of this weight map holds some significant features in them. Luminance weight map quantifies the visibility of each pixel based on the information of RGB channel by assigning higher value to the pixel with better visibility and lower values to rest of the pixels. Chromatic weight map controls the saturation gain by calculating the difference between the saturation of each pixel

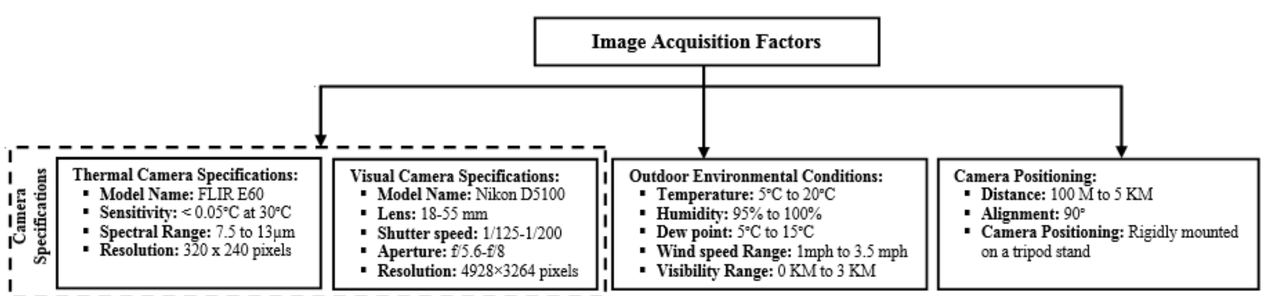

Fig. 1 Camera Setup and Acquisition Factors for Capturing Natural Scene Images of SAMEER-TU Database

and the maximum saturation range. The last weight map is Saliency weight map [36] that identifies the degree of conspicuousness with respect to the neighbourhood regions. Combining the Laplacian pyramid representation of the input with the Gaussian pyramid representation of the normalized weights, the restored image is derived.

B. Filtering based strategy

The filtering based strategy [25] for enhancement of weather degraded images is based on the two observations. The first observation is that there is an exponential decline of the intrinsic luminance and colors and the second observation is that the addition of a white atmospheric veil is an increasing function of the object distance from the viewer. The algorithm generally consists of approximation of atmospheric veil, image restoration and smoothing followed by tone mapping to maintain color fidelity. In the first step towards enhancement, local white balancing is performed prior to inferring atmospheric veil as a pre-processing step by biasing towards local image averages. After pre-processing, the atmospheric veil is inferred by assuming two constraints (i.e. it is positive and is not higher than the minimum component of the input image) and a filter named Median of Median Along Lines is introduced for smoothing the scenes while preserving the corners. It has been observed that the restored images usually have higher dynamic than the original one. So a tone mapping is done to the restored image as a post-processing so that the resulting image comparatively have same aspects compared to the original image.

C. Dark channel prior based strategy

The Dark Channel Prior based strategy [12] for restoration of weather degraded is based on the observation that in most of the non-sky regions there are some pixels which have low intensity in atleast one of its RGB color channel. These dark pixels mainly occurs due to airlight and hence can provide an estimation of the thickness of haze in the image. Due to the presence of airlight, a haze image is brighter than its haze-free version and will have higher intensity in areas with more haze. Based on this statistics, first the transmission is estimated by applying the minimum operation in the local patch on the haze imaging equation [37]. Then refinement of the transmission is carried out using soft matting method [38] to recover the scene radiance by estimating the atmospheric light from the most haze-opaque pixel and hence restore the visibility of the images.

D. Structure-Texture decomposition based strategy

The structure-texture decomposition strategy [26] is based on generating two layers i.e. structure and texture layers from the original input image to eliminate the artifacts of compression that are expanded in the image contrast. In the first step, structure layer is obtained by applying bilateral filter [17] operation in the input image and then generated the texture layer by calculating the difference between the input image and its structure layer. After decomposition, contrast enhancement based on Rudin-Osher-Fatemi method [39] is directly applied to the structure layer. On the otherhand to reduce the compression artifacts in the texture layer, refinement is carried out by applying the discrete cosine transform (DCT) to each 8×8 patches in the texture layer and used soft matting technique [12] to represents the most likelihood scene details. After removing the artifacts, layer recomposition is carried out by simply adding these two layers and amplified the textual results by a factor of 10 and shift it by +0.5 for better visualization.

E. Bayesian probabilistic strategy

The Bayesian probabilistic strategy [27] for restoring the appearance of true scene is based on modelling the image using a factorial Markov random field (FMRF) [40] in which the scene albedo and depth information are two independent hidden layerto mutually estimate them. According to the inherent bilinearity of Koschmieder's law [37], both the scene albedo and depth play a significant part in estimation of scene appearance those are degraded by atmospheric conditions. Due to this reason, FMRF is introduced with a probabilistic graphical model to find the dependence between these two variables and the input image and integrated appropriate constraints as statistical priors on each of this variable. Then expectation maximization principal is adopted in original FMRF algorithm using conventional graph-cuts algorithms for factorization of the input image into the scene albedo and scene depth layer.

F. Boundary Regularization based strategy

The regularization strategy [28] is based on introducing a new contextual regularization on scene transmission by incorporating filter banks that reduces the noise while enhancing important image structure like edges and corners. In this method, assuming that the transmission function as obtained by He et.al.'s method [12] in a local image patch is constant, patch-wise transmission is estimated by applying a maximum filtering on its lower bound constraint. But, this contextual assumption often fails when there is an abrupt changes in the depth information and hence introduce a weighted L1-norm function on the constraints to reduce the negative influence of halo artifacts in the dehazing results. After that the atmospheric light obtained by He et.al.'s method [13] is modified by filtering each color channel of an input image using a moving window based minimum filter. Then the maximum value of each color channel is taken to estimate the airlight component and hence the enhanced image is obtained.

G. Stochastic enhancement strategy

The stochastic enhancement strategy [29] for restoration of weather degraded images estimates a visibility map from the input image prior to stochastic iterative algorithm. In this method, the visibility map is estimated by applying bilateral filter in the gradient magnitude of intensity image. Based on the fact that the presence of fog or haze intrinsically move the intensity value towards white at a particular pixel location and applying any enhancement algorithm directly may lead to saturation. For this reason, enhancement is carried out in the negative image of V plane of the HSV representation and the V plane is decomposed by Singular Value Decomposition (SVD) to preserve the textural information and hence restored the images.

Fig. 2 depicts the displayed results of these seven enhancement techniques on SAMEER-TU database in terms of restoring the visibility of the scenes.

V. Performance Evaluation Measures

Measuring the perceptual quality of image by subjective experimentation is time-consuming and hence quantifying the quality of an image using an objective quality assessment metrics that agrees with the human observer is a fundamental need of image processing. For instance, the quality assessment metrics of image restoration techniques are broadly classified into two categories i.e. reference based and no-reference based image quality assessment based on the amount of information

Fig. 3 Comparison of the Recent Enhancement Techniques (a) Original Images; and the displayed results of (b) Ancuti et.al. [9]; (c) Tarel et.al. [25]; (d) He et.al. [12]; (e) Li et.al. [26]; (f) Nishino et al. [27]; (g) Meng et.al. [28]; (h) Bhattacharya et.al [29]

needed from the reference image. The brief description of each category of these metrics are given below:

A. Reference Based Quality Assessment Metrics

The reference image based quality assessment metrics is applicable when the reference image is fully available [41]. The quality assessment of the enhancement algorithms based on reference methods are suppose to be better since this method has the complete information about the reference image.The seven reference based qualitative assessment metrics [42] i.e. Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Normalized Cross Correlation (NCC), Average Difference (AD), Structural Content (SC), and Normalized Absolute Error (NAE) are used in our study to physically quantify each of these enhancement algorithms in terms of quality of the images after restoration. Higher value of PSNR and lower values of MSE, SC, NCC, AD, NAE and MD indicates more similarity of the restored images with respect to the reference image.

B. No-Reference Based Quality Assessment Metrics

In many real-world applications, the reference image may not beavailable and the quality evaluation is solely based on the test image. Non-Reference image based qualitative assessment metrics assess the quality of an image without any information of the reference image. Some of the eminent non-reference qualitative assessment metrics proposed in the literature i.e. Rate of New Visible Edges (e), Mean Ratio (σ), Percentage of Pixels (r) [43], Local Block Based FISH (LBBFISH) [44] are used to assess the quality of images after restoration. A better enhanced image generally have higher values of e, r and LBBFISH and lower value of σ.

VI. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Qualitative Analysis

The effectiveness of different enhancement techniques as demonstrated in Section IV is carried out in terms of reference and non-reference qualitative assessment methods and execution time. Experiments have been conducted on 520 randomly selected images from SAMEER-TU Database degraded due to the presence of fog. The average value of this qualitative assessment metrics for restoring the visibility of fog degraded images as shown in Fig.3 are shown in TABLE III.

Fig.4, represents the Box-Whisker plot for comparison of the enhancement techniques on SAMEER-TU Database. In each boxplot (i.e. Fig. 4 (a) to (j)), the X-axis represents the used techniques (i.e. 1 represents Ancuti et.al. [9], 2 represents Tarel et.al. [25], 3 represents He et.al. [12], 4 represents Li et.al. [26], 5 represents Nishino et.al. [27], 6 represents Meng et.al. [28] and 7 represents Bhattacharya et.al. [29]) and Y-axis represents the median based plot related to the quality assessment metrics. In this non-parametric plot, each box is enclosed by first and third quartiles to represent groups of numerical data and is divided into two parts by the median value represented as red lines on Y-axis. The outliers (represented by red asterisks) in the plot shows the extreme variability of the quality assessment metrics in the dataset. It can be observed from Fig. 4, that the fusion based method and stochastic enhancement method proposed by Ancuti et.al. [9]

TABLE VI

QUALITATIVE COMPARISON OF FIVE IMAGES AS SHOWN IN FIG.3 BASED ON COMPUTATIONAL TIME, REFERENCE AND NO-REFERENCE QUALITY ASSESSMENT METRICS

Author/ Year	Performance Evaluation Measures										Computational Time (in secs)
	Reference Based Quality Assessment						No-Reference Based Quality Assessment				
	MSE	PSNR	NCC	AD	SC	NAE	e	σ	r	LBBFISH	
Ancuti et.al. [9]	**1.75E+03**	**15.9415**	**0.5802**	**26.6338**	**0.6490**	**0.2819**	**0.9194**	**0.0002**	**4.9008**	**21.5759**	**4.6387**
Tarel et.al. [25]	4.29E+03	12.2973	0.9936	37.4939	1.3992	0.4759	0.5923	0.0398	2.7197	17.7585	22.8968
He et.al. [12]	3.18E+03	13.4894	0.9069	34.2105	0.9702	0.4110	0.8713	0.0021	2.8833	20.5605	21.3738
Li et.al. [26]	3.20E+03	13.2208	0.9096	35.7062	1.3431	0.4201	0.6784	0.0029	2.9209	19.8132	43.1457
Nishino et al. [27]	5.02E+03	11.6715	1.2016	50.5234	2.3727	0.4939	0.5144	0.0089	1.7446	17.4721	47.4830
Meng et.al. [28]	6.95E+03	11.4736	1.2108	54.1961	5.6571	0.5515	0.3842	0.0484	1.6727	16.8261	**11.5716**
Bhattacharya et.al [29]	**2.68E+03**	**14.5036**	**0.8233**	**30.1749**	**0.6221**	**0.3651**	**0.9078**	**0.0005**	**4.6621**	**22.0799**	13.3503

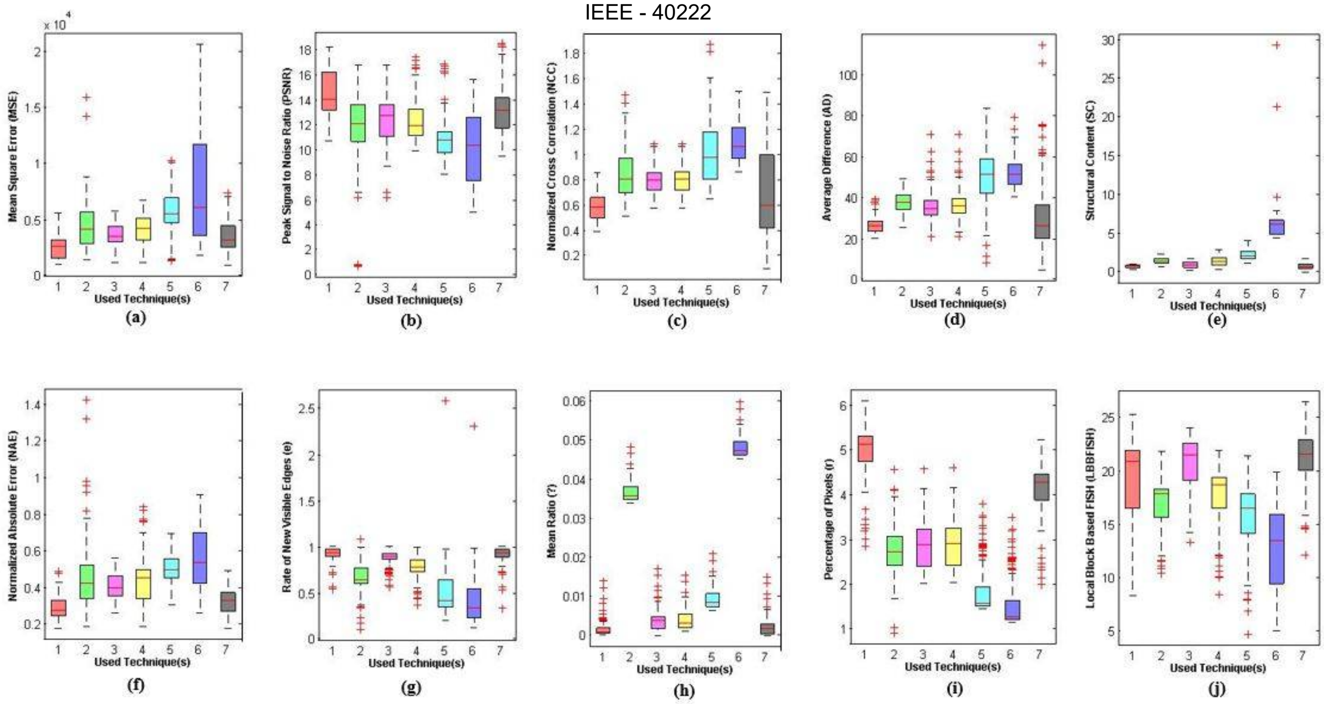

Fig. 4 Box–Whisker Plot for Qualitative Comparison of Visibility Enhancement Techniques on SAMEER-TU Database: (a) Mean Square Error (MSE) (b) Peak Signal to Noise Ratio (PSNR); (c) Normalized Cross Correlation (NCC); (d) Average Difference (AD); (e) Structural Content (SC); (g) Normalized Absolute Error (NAE); (h) Rate of New Visible Edges (e); (i) Mean Ratio (σ); (j) Percentage of Pixels (r); (k) Local Block Based FISH (LBBFISH)

and Bhattacharya et.al. [29] have lower median value for MSE, SC, NCC, AD, NAE, MD and σ and higher median value for PSNR, e, r and LBBFISH in comparison to the remaining five methods and hence indicates more resemblance of the restored images with respect to the original images in clear day and human judgments. Conversely, the results of Bayesian probabilistic method and boundary constraint as proposed by Nishino et.al. [27] and Meng et.al. [28] are negatively correlated to the above outer performed methods as shown in Fig. 4 and hence results in low quality images after restoration.

B. *Computational Time Efficiency*

In order to evaluate the execution time of these visibility enhancement techniques, 520 randomly selected images are tested and the specification of the workstation is Intel Core i5 CPU with 8GB RAM. The size of each images are resized to 500×500 pixels. From Fig. 5 it is clear that, the method of Ancuti et.al. [9], Meng et.al. [28] and Bhattacharya et.al [29] needs less execution time (i.e. 5.0771 secs, 12.6202 secs and 14.9815 secs on average respectively) to process all these images whereas the method of Nishino et.al. [27] comparatively takes more time (i.e. 51.4235 secs on average) to process all these images.

From this comparative analysis, it is found that although the enhancement techniques as proposed by Meng et.al. [28] needs less time to process all the images but with respect to qualitative comparison these method underperforms and is not effective to restore the visibility of the scene. On the other hand, dehazing method proposed by Ancuti et.al. [9] and Bhattacharya et.al [29] outperforms the remaining five methods both qualitatively and quantitatively. Also these methods are efficient to remove haze from images and do not require any scene depth information, user intervention and avoid complicated atmospheric scattering model.

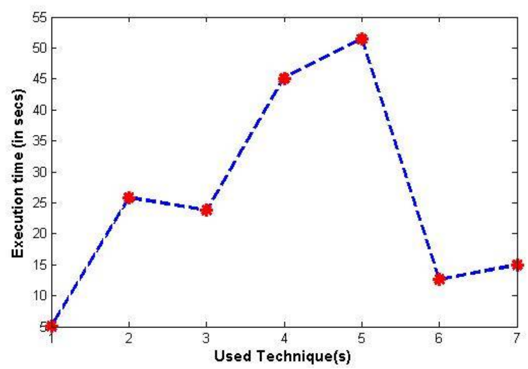

Fig. 5 Execution Time of Visibility Enhancement Techniques on SAMEER-TU Database

VII. CONCLUSION

The images of outdoor scenes are often drastically altered by bad weather conditions that significantly degrades the visibility of the acquired scene. Enhancement of those images taken in specific atmospheric conditions has been an increased interest among research in image processing. In this paper comparative analysis of some well-known image enhancement techniques on SAMEER-TU database is carried out in terms of quality assessment metrics proposed in the literature. The achieved result shows that these methods not only enhance the image contrast effectively but also preserve the fine details of the image. Studies so far indicate that, the critical review and comparative study can be a valuable contribution to develop new algorithms for visibility enhancement and comparison of this method with the state of art in future.

ACKNOWLEDGMENT

The work presented here is being conducted in the Thermography Facility Laboratory of Computer Science and Engineering Department of Tripura University (A central university), Tripura, Suryamaninagar-799022. The research work was supported by the Grant No. SMR/PD(R)/ NER/2012-13/Thermography, Dated: 22nd March 2011 from the Society for Applied Microwave Electronics Engineering and Research (SAMEER), Government of India.

REFERENCES

[1] 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.

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

[3] 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.

[4] R.C. Henry, S. Mahadev, S. Urquijo and D. Chitwood, "Color perception through atmospheric haze," JOSA A, Vol. 17, No. 5, pp. 831-835, 2000.

[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] M.I. Daily, T. Farr, C. Elachi, and G. Schaber, "Geologic interpretation from composited radar and Lands at imagery," 1979.

[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] 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.

[14] J.B. Wang, N. He, L.L. Zhang and K. Lu, "Single image dehazing with a physical model and dark channel prior," Journal of Neurocomputing, Vol. 149, Elsevier, pp. 718-728, 2015.

[15] 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.

[16] H. Xu, J. Guo, Q. Liu, and L. Ye, "Fast image dehazing using improved dark channel prior," 2012 International Conference on Information Science and Technology (ICIST), IEEE, pp. 663-667, 2012.

[17] C. Tomasi and R. Manduchi, "Bilateral filtering for gray and color images," Sixth International Conference on Computer Vision, IEEE, pp. 839-846, 1998.

[18] Y. Wang, and W. Bo, "Improved single image dehazing using dark channel prior," 2010 IEEE International Conference on Intelligent Computing and Intelligent Systems (ICIS), Vol. 2, IEEE, pp. 789-792, 2010.

[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] A.K. Tripathi, and S. Mukhopadhyay, "Single image fog removal using bilateral filter," 2012 IEEE International Conference on Signal Processing, Computing and Control (ISPCC), IEEE, pp. 1-6, 2012.

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

[24] H. Zhang, P. Zhou, M. Xue, F. Yang, and Q. Yang, "Single fogged image restoration using improved mean shift filtering," 4th International Congress on Image and Signal Processing (CISP), Vol. 2, IEEE, pp. 803-806, 2011.

[25] J.P. Tarel and N. Hautiere, "Fast visibility restoration from a single color or gray level image," IEEE 12th International Conference on Computer Vision, IEEE, pp. 2201-2208, 2009.

[26] Y. Li, F. Guo, R.T. Tan and M.S. Brown, "A contrast enhancement framework with JPEG artifacts suppression," European Conference on Computer Vision, Springer International Publishing, pp. 174-188, 2014.

[27] K. Nishino, L. Kratz, and S. Lombardi, "Bayesian defogging," International Journal of Computer Vision, Vol. 98, No. 3, pp. 263-278, 2012.

[28] G. Meng, Y. Wang, J. Duan, S. Xiang and C. Pan, "Efficient image dehazing with boundary constraint and contextual regularization, "IEEE International Conference on computer vision, IEEE, pp. 617-624, 2013.

[29] S. Bhattacharya, S. Gupta and K. S. Venkatesh, “Dehazing of color image using stochastic enhancement,” IEEE International Conference on Image Processing (ICIP), IEEE, pp. 2251-2255, 2016.

[30] M.K. Bhowmik, K. Saha, P. Saha and D. Bhattacharjee, “DeitY-TU face database: its design, multiple camera capturing, characteristics, and evaluation.” Journal of Optical Engineering, Vol. 53, No. 10, SPIE, pp. 102106-102106, 2014.

[31] A. Savran et al., “Bosphorus database for 3D face analysis,” European Workshop on Biometrics and Identity Management, Springer Berlin Heidelberg, pp.47-56, 2008.

[32] R. Gross, I. Matthews, J. Cohn, T. Kanade and S. Baker, “Multi-pie,” Image and Vision Computing, Vol. 28, No. 5, Elsevier, pp. 807-813, 2010.

[33] P.J. Phillips, H. Wechsler, J. Huang and P.J. Rauss, “The FERET database and evaluation procedure for face-recognition algorithms.” Image and Vision Computing, Vol. 16, No. 5, pp. 295-306, 1998.

[34] S.F. Samariaand A.C. Harter, “Parameterisation of a stochastic model for human face identification,” Second IEEE Workshop on. Applications of Computer Vision, IEEE, pp. 138-142, 1994.

[35] T. Pal, M.K. Bhowmik and A.K. Ghosh, “Defogging of Visual Images Using SAMEER-TU Database,” Procedia Computer Science. Elsevier, pp.1676-1683, 2015.

[36] R. Achanta, S. Hemami, F. Estrada and S. Susstrunk, "Frequency-tuned salient region detection," IEEE International Conference on Computer Vision and Pattern Recognition (CVPR 2009),IEEE, pp.1597–1604, 2009.

[37] H. Koschmieder, "Theory of horizontal eyeshot: contrast and eyeshot," Germ & Nemnich, 1925

[38] A. Levin, D. Lischinskiand Y. Weiss, “A closed-form solution to natural image matting," IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 30, No. 2, pp. 228-242, 2008.

[39] L.I. Rudin, O. Stanley and E. Fatemi, "Nonlinear total variation based noise removal algorithms," Physica D: Nonlinear Phenomena, Vol. 60, pp. 259-268, 1992.

[40] J. Kim and R. Zabih, “Factorial markov random fields,” European Conference on Computer Vision, Springer Berlin Heidelberg, pp. 321-334, 2002.

[41] Z. Wang, A.C. Bovik, H.R. Sheikh and E.P. Simoncelli, “Image quality assessment: from error visibility to structural similarity,” IEEE Transactions on Image Processing, Vol. 13, No. 4, pp. 600-612, 2004.

[42] R. Sakuldee and S. Udomhunsakul, "Objective performance of compressed image quality assessments," International Journal of Computer Science, Vol. 2, No. 4, pp. 258-267, 2007.

[43] N. Hautiere, J.P. Tarel, D. Aubert and E. Dumont, "Blind contrast enhancement assessment by gradient ratioing at visible edges," Image Analysis & Stereology, Vol. 27, No. 2, pp. 87-95, 2011.

[44] P.V. Vu and D.M. Chandler, "A fast wavelet-based algorithm for global and local image sharpness estimation," IEEE Signal Processing Letters, Vol. 19, No. 7, pp. 423-426, 2012.