Visibility Enhancement Techniques for Fog Degraded images: A Comparative Analysis with Performance Evaluation

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***Abstract*—Low visibility is regarded as the fundamental cause for increasing number of accidents. When bad weather condition exists mainly due to fog, haze, snow, darkness, etc., the driver is unable to observe a distinct view of route. Out of the bad atmospheric condition, fog is one of the major sources of the accident because the visibility of fog remains very low which is less than 1 km. It is the natural phenomenon that decreases the contrast and color fidelity of objects in the captured image and makes the object difficult to see through naked eyes. The main goal of this paper is to perform a comparative analysis of some well-known visibility enhancement techniques. This paper also implemented three well-known fog removal algorithms, and for assessing the efficiency of the methods used, qualitative assessment evaluation is accomplished along with comparative statistical analysis and algorithms efficiency comparison.**

Keywords— Fog removal; comparative study; image enhancement; performance evaluation.

I. Introduction

Analysing and estimating the appearance of outdoor scenes under arbitrary lighting and weather conditions is a serious problem in computer vision. Solutions to this problem have entanglement for several computer vision applications such as visual surveillance, tracking, intelligent vehicles, and remote sensing. The appearance of an outdoor image mainly relies on several atmospheric factors like clear air, mist, haze fog, rain, etc. This paper presented a comparative analysis of some classical fog removal algorithms and implemented these techniques on real time foggy images along with performance evaluation.

Recently, visibility enhancement techniques have emerged as an effective role in numerous computer vision based applications that employed in different atmospheric conditions. Various techniques of dehazing have been presented by various researchers to enhance the visibility in haze degraded images. These techniques are classified into three main groups: 1) additional information dehazing approaches; 2) multiple image dehazing approaches, and 3) single image dehazing approaches.

II. Review on Different Image dehazing techniques

Image Dehazing approaches under the category of ***additional information dehazing approaches*** involve scene information to eliminate haze and restore the color fidelity. Srinivasa G. Narasimha et al. [1] presented an efficient and inclusive set of models, methods, and dataset of images for effective perception of images in poor atmospheric environment. These models are classified into single scattering model and multiple scattering models. By using these models, scene properties, such as 3D structure, scene contrasts and colors can be recovered. Yi-shuzhai et al. [2] presented an algorithm to enhance contrast in the fog degraded image by utilizing a moving template. This algorithm employs sub-block histogram equalization to increase the contrast in every template with the assumption that the pixel values within a template contain the identical scene depth. The algorithms based on additional approaches requires some other operations, such as finding out the elevation, tilt, or location of the camera, or by manually calculating the distance between the vanishing point of a captured image and the sky area, or by an approximation of 3-D geometrical model of the input image. So, these approaches do not show good results in arbitrary images for real time applications.

Haze removal techniques under the category of ***multiple image dehazing approaches*** involve multiple images to eliminate haze from the degraded images and to determine depth of the scene. Schechner et al. [3] presented a technique that involves multiple images of the similar scenery with various polarization degrees for enhancing the color fidelity of degraded images. Robby T. Tan et al.[4] presented a novel and comprehensive technique to dehaze image. This technique is deployed on two fundamental observations. In first observation, images with higher visibility have better contrast than images affected by poor weather, where as in second observation, variation of airlight generally relies on between the distance of objects and observer. These methods eliminate haze by making a comparison of two or more images that have been taken in various atmospheric conditions and can estimate scene depth. However, the haze removal techniques involving multiple image approaches need additional cost or hardware to accomplish efficiently.

Recently, researchers have concentrated on ***single-image dehazing approaches***, that do not require scene depth details and ignore complex atmospheric scattering model. Tarel et al. [5] described a method that restores hazy images by increasing the local contrast of degraded hazy input image as it is observed that haze-free image posses better contrast than the haze degraded image. This method shows good results but sometimes the output images may posses some artifacts nearby depth discontinuities. Jingyu et al. [6] proposed a method based

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on physics based model to produce a series of virtual images and later combined these virtual images to enhance the contrast in the image using wavelet fusion technique. Their restoration technique does not depend on predicted structure, scene reflectance distributions, or thorough information regarding the exact weather condition. It can also deal with the scenario without a reference image. He et al. [7] presented a simple and efficient dark channel prior method to eliminate haze from the original degraded image. The dark channel prior depends on a crucial observation that most local regions in haze-free outdoor images possess some pixels whose intensity is considerably less in at least one RGB channel. The thickness of the haze can directly be predicted using this technique, and a better-quality haze-removal image can be regained. Indrit Enesi et al. [8] presented a novel approach to dehaze image. In this algorithm, prior details of scene structure, scene reflectance distribution, or thorough information of the exact atmospheric condition are not required. This method can be implemented on grayscale image, color image, infrared images, and multispectral images. Tripathi et al. [9] have proposed an efficient image dehazing algorithm based on bilateral filter which is used for air light estimation. It can handle both colors and gray images, and it was observed that estimation of airlight map relies on the distance between the objects of the scene and observer. By using this technique, the estimated airlight map can detect the discontinuities present over the edges within the objects. Odruta Orniana Ancuti et al. [10] presented a fusion-based approach for enhancing the distorted image in poor visibility conditions. In this paper single-image based strategy is used based on multi-scale fusion that can accurately enhance the distorted images using only the original degraded information.

After a rigorous survey, it is found that Tarel et al.'s [5] approach, He et al.'s [7] approach and Ancuti et al.'s approach [10] are most simple and effective methods for single image dehazing as these methods do not require the knowledge of depth of scene, user intervention as well as ignore complex atmospheric scattering model and can effectively remove haze from images.

The organization of remaining phase of paper is described as follows. In Section II, different techniques for image dehazing has been reviewed, Section III concerns with the implementation of three well-known techniques for improving the visibility of foggy image, Section IV deals with Experimental Result and Discussion in addition to Qualitative Assessment Evaluation, Comparative Statistical Analysis, and Algorithms Efficiency Comparison. Finally, section V concludes this work.

III. Implementation of three well known dehazing techniques

A. Technique based on fusion based strategy

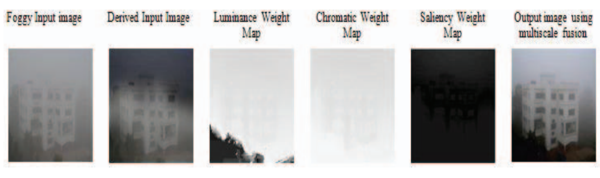
The technique used in this paper is fusion based strategy performed in multi scale manner for improving the visibility of the degraded scenes in low visibility conditions [10]. The key theory behind this fusion based technique rests on the fact that two input images are derived from the input image with the objective of retrieving the visibility for every single region of the image in at least one RGB channel. Furthermore, this fusion based dehazing technique approximates for every single pixel the desired attributes known as weight maps that command the involvement of every input to the outcome.Thus, in this fusion based approach, the derived inputs are weighted by three weight maps i.e. luminance weight map, chromatic weight map and saliency weight map that focus to retain the areas with high visibility. **The *Luminance weight map*** is used to measure the visibility of every pixel, and this map allocates high values to areas with higher visibility and provides smaller values to the remaining region. This weight map is derived out mainly due to color channel information, and this is found out based on the deviation between RGB channel and luminance from the derived input image[10]. But, it has been noticed that this weight map reduces contrast globally and color fidelity. To overcome this problem, two more weight maps: chromatic map and saliency map have been defined for controlling the color fidelity and global contrast respectively. The ***Chromatic weight map*** is introduced to handle the saturation level in the output image, and it is derived as the distance between its saturation level and maximum saturation range [10]. This chromatic weight map is prompted from the aspect that normally humans favor images that posses high saturation level.The ***Saliency weight map*** is used to identify the degree of distinctness compared to the nearby areas, and this map determines how much a particular object is different from remaining areas of the image, or from surrounding areas. But by employing these weight maps, sometimes the output image posses some artifacts. To overcome this limitation, Laplacian pyramid integrated with Gaussian pyramid representations of normalized weights are used for enhancing the haze degraded image to its clear form as much as possible. Experiments conducted in each step by fusion based approach [10] are depicted in Fig. 1.

B. Technique based on dark channel prior

The second technique that is used here is the dark channel prior technique to improve the visibility of fog degraded image. Generally, in the local regions of a scene that do not possess the sky area, some pixels called as dark pixels are present whose intensity is very less in at least one RGB channel.These dark pixels provide the estimation of transmission of haze [7]. This technique shows good results in dense hazy condition. By employing this technique, atmospheric airlight can be estimated in the haze free image to fetch a further accurate result. This technique is generally used for the images having no sky region, as minimum one RGB channel possess very less intensity in some pixels. The low intensity in the RGB channel is predominant because of three issues such as Colorful items, shadows, and dark items. It has been observed that if the outdoor images consist of shadows and colorful, the dark channels of these images becomes dark as because of fog, a hazy image is brighter than its image of no haze. Therefore it can be concluded that dark channel of hazy image will posses a higher intensity pixel values in the areas with more haze. Therefore, visually the dark channel's intensity is an approximate estimation of haze thickness. If the haze imaging model and soft matting interpolation technique are combined, then a better-quality haze removal image can be recovered to produce a good depth map. Experiments conducted in each step by dark channel prior approach [7] is shown in Fig. 2.

C. Technique based on white balance, gamma correction and tone mapping

Tarel et al. [5] described a technique based on fast visibility restoration from a single color or gray level image. Koschmieder in 1924 established a model based on the effect of fog on gray level image which states the relation of the apparent contrast of an object against a sky-background, at a specified distance of observation to the inherent contrast to the atmospheric transmissivity. Based on the law, Tarel et al.[5] proposed a visibility enhancement technique with less complexity for color as well as gray images, which acquire white balancing, gamma correction, and tone mapping to retain color information. However, by implementing this technique on some degraded images, the results sometimes show high-level residual haze. Experimental result of this method has been shown in Fig. 3.



(a) (b) (c) (d) (e) (f)

Fig. 1. (a) Foggy input image (b) Corresponding derived input image (c)Corresponding Luminance Map of enhanced image (d)Corresponding Chromatic Map of enhanced image (e) Corresponding Saliency Weight Map of enhanced image (f) Fog-free output image by performing multiscale fusion [10].

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

Fig. 2. (a) Real time fog degraded input image (b) Corresponding image using Dark Channel Prior (c) Corresponding image using Soft Matting (d) Corresponding image using Scene Radiance (e) Final output image.[7].

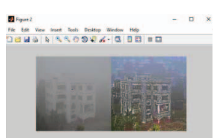


Fig. 3. Enhanced image using Tarel's method [5].

Fig. 4. Experimental results of different dehazing approaches of Tarel et al.[5], He et al. [7], and Ancuti et al. [10].

IV. Results and Discussion

Experiments have been carried out on 200 real time images captured in an outdoor environment in dense foggy weather on our own database [11] [12] and also on some benchmark fog images collected from a variety of sources [5] [7] [10]. Fig. 4 shows experimental results of different dehazing approaches. It is observed that by using these techniques, the contrast is increased in the captured fog degraded images and thus the visibility of the images is enhanced.

The next stage of the experiment demonstrates a qualitative assessment evaluation or performance evaluation based on non-reference and reference methods on the fog degraded images to examine the efficiency of these methods.

A. Qualitative Assessment Evaluation

Qualitative Assessment Evaluation is conducted based on non-reference methods and reference methods, and it has been noticed that using these methods the quality of the restored image is much effective than the original fog degraded image. We have implemented these assessment techniques on the color images of size 200*200. Qualitative Assessment Evaluation is performed on these images based on 1) Non-reference methods and 2) Reference methods.

1) Non-reference Methods:

Non-reference Methods assess the quality of the image without a reference image. These algorithms determine the quality of the image without any knowledge of reference image and correlate well with human perception. This paper uses three well-known non-reference methods: e, σ, and $\bar{r}$ [13] to evaluate the restoration efficacy of the scenes taken in poor weather conditions. Metric e estimates the capacity of each compared technique for retrieving the edges between the output and input image. To evaluate the average visibility enhancement, the $\bar{r}$ metric signifies the average gradient before and after regaining the haze degraded images. Finally, the σ metric determines the ratio for finding the visible edges of the restored haze-free image.

a) Increased rate of visible edges-

The first two indicators (e, $\bar{r}$) of the blind assessment use the enhanced degree of image edges to represent the enhanced degree of the image visibility [13]. The first indicator e denotes the increased rate of visible edges after image defogging and is calculated by-

$$e = \frac{n_r - n_0}{n_0} \tag{1}$$

where n_r and n_o represent the cardinal numbers of the set of visible edges in restored image I_r and original input image I_o respectively. The larger the e, the larger degree of visibility improvement. This indicator uses the increased number of visible edges to represent the higher degree of visibility in the image.

b) Restoration degree of the image edge and texture information-

The second indicator $\bar{r}$ uses the enhanced degree of image gradients to represent the restoration degree of edge and texture details. A larger $\bar{r}$ also means that the corresponding defogging algorithm has better edge preservation performance than others. $\bar{r}$ is calculated as

$$\bar{r} = \exp\left[\frac{1}{n_r}\sum \log r_i\right] \tag{2}$$

Where $r_i = \Delta I_i^r / \Delta I_i^0$

ΔI^r are the gradient of restored image and ΔI^0 is original image, respectively.

This gradient based index can also be used as an index to measure the restoration of edge information.

c) Percentage Of The Number Of Saturated Pixels (σ)

The high value of contrast gain indicates good performance. However, contrast gain must not be so high that part of the restored image become saturated, that is, either entirely black or white. Percentage of the number of saturated pixels (σ) is given as-

$$\sigma_y = \frac{n}{M * N} * 100 \tag{3}$$

where *n* indicates the number of pixels that gets into saturation in the output image. *M, N* denote the dimensions of the image. If the number of saturated pixels (σ) is low, it signifies good performance of the visibility enhancement algorithm.

2) Reference methods-

Reference methods use a reference image for assessing the quality of the distorted image. Since this method has the complete information about the reference image, the results of reference methods are supposed to be superior to other qualitative assessment algorithms [14] [15]. Some well-known reference methods that are commonly used for assessing the quality of an image are explained below.

a) Mean Square Error(MSE)-

MSE is derived using following equation [14][15]-

$$MSE = \frac{1}{MN}\sum_{(m.n)}(I_{m,n} - \overline{I_{m,n}})^2 \tag{4}$$

where $M N$ represents the dimensions of the image.

$I_{m,n}$ indicates original image and $\overline{I}_{m,n}$ is restored image.

Higher MSE indicates that the image is of poor quality.

b) Peak Signal To Noise Ratio (PSNR)-

PSNR is computed using following equation [14] [15]-

$$PSNR = MN \max_{m,n} I_{m,n}^2 / \sum_{m,n}(I_{m.n} - \overline{I_{m,n}})^2 \tag{5}$$

Here *max* represents maximum pixel value of image, and the pixel is denoted by using 8 bits per sample.

Higher PSNR indicates that the image is of high quality.

c) Normalized Cross Correlation (NCC) -

NCC is represented using the following equation [14] [15]-

$$NCC = \sum_{(m.n)} I_{m,n}, \overline{I_{m,n}} / \sum_{(m.n)} I^2_{m,n} \tag{6}$$

NCC close to 1 means the reference image is close to the original image.

d) Average Difference (AD):

AD represents the average of difference between the reference signal and the test image and it is stated by the equation [15]-

$$AD = 1/MN \sum_{i=1}^{M}\sum_{j=1}^{N}((x(i,j) - y(i,j)) \tag{7}$$

Lower AD value indicates that the image is of good quality.

e) Structural Content (SC):

Structural Content (SC) is denoted using the following equation [15]-

$$SC = \sum_{(m.n)} I^2_{m,n} / \sum_{(m.n)} \overline{I}^2_{m,n} \tag{8}$$

The large value of SC indicates the image is poor quality.

f) Maximum Difference (MD):

MD denotes the maximum of the error signal which is computed by the difference between the reference image and test image and is specified by the equation [15]-

$$MD = Max\,|x(i,j) - y(i,j)| \tag{9}$$

Lower MD value indicates that the image is of high quality.

g) Normalized Absolute Error (NAE):

NAE signifies an average of the absolute difference between the reference image and test image. It is given by the equation [15]-

$$NAE = \sum_{(m.n)} \left|I_{m,n} - \overline{I_{m,n}}\right| / \sum_{(m.n)} I_{m,n} \tag{10}$$

If the value of NAE is large, then the image will be of poor quality.

TABLE I. PERFORMANCE EVALUATION OF DIFFERENT DEHAZING TECHNIQUES VIA NON REFERENCE METHODS

Image	Evaluation	Tarel et al. 's method [5]	He et al.'s Method [7]	Ancuti et al.'s Method [10]
Image 1	e	0.25082	0.38765	0.64422
	σ	0	0	0
	$\bar{r}$	1.5482	1.6067	1.85082
Image 2	e	0.19045	0.012697	0.031851
	σ	0	0.31	0.2175
	$\bar{r}$	1.7207	0.8014	0.9013
Image 3	e	0.1821	0.17734	0.28978
	σ	0	0.0015	0
	$\bar{r}$	1.1951	1.5267	1.8498
Image 4	e	0.023949	0.081963	0.050388
	σ	0	0.0025	0.0014
	$\bar{r}$	0.86077	1.6606	1.946
Image 5	e	0.16929	0.1744	0.2479
	σ	0	0	0
	$\bar{r}$	1.2613	1.3177	1.5697

TABLE II. PERFORMANCE EVALUATION OF DIFFERENT DEHAZING TECHNIQUES VIA REFERENCE METHODS

Image	Evaluation	Enhanced Image by Tarel et al.'s Method [5]	Enhanced Image by He et al.'s Method [7]	Enhanced Image by Ancuti et al.'s Method [10]
Image 1	MSE	1.6118e+03	1.3843e+03	1.0691e+03
	PSNR	16.0577	16.7186	17.8406
	NCC	1.0809	0.7614	0.5241
	AD	-31.9807	28.1552	-26.1440
	SC	0.7752	0.6679	1.0691e+03
	MD	88	114	17.8406
	NAE	0.2850	0.2558	0.5241
Image 2	MSE	4.3206e+03	5.1173e+03	3.9332e+03
	PSNR	10.8712	9.6077	15.2681
	NCC	1.4029	1.2607	0.4209
	AD	-52.5348	80.1534	-31.8905
	SC	0.4117	1.2038	0.2960
	MD	132	144	52
	NAE	0.7531	0.5869	0.3531
Image 3	MSE	3.0588e+03	3.2353e+03	2.2475e+03
	PSNR	13.2753	13.0316	14.6138
	NCC	1.4318	1.2255	0.5710
	AD	-39.9574	51.6566	-29.0665
	SC	0.9519	0.6950	0.4368
	MD	132	116	89
	NAE	0.5455	0.4304	0.4354
Image 4	MSE	3.3245e+03	3.2874e+03	2.0114e+03
	PSNR	12.9135	12.9622	18.0818
	NCC	1.1154	1.1038	0.6494
	AD	-32.1998	53.6717	-21.6407
	SC	0.7548	1.1771	0.6971
	MD	201	118	47
	NAE	0.4010	0.3822	0.2114
Image 5	MSE	1.7506e+03	1.5916e+03	1.2916e+03
	PSNR	15.6990	16.1125	18.4615
	NCC	1.2178	1.0729	0.7174
	AD	-27.8936	37.1441	-11.1017
	SC	0.8257	0.7955	0.6255
	MD	125	90	46
	NAE	0.3268	0.2917	0.1938

B. Comparative Statistical Analysis

Comparative Statistical Analysis is performed on some benchmark fog images collected from a variety of sources [5] [7] [10] from the results obtained from Tan et al.' s technique, He et al.'s technique and Ancuti et al.'s technique. From Table I we can see that, although the rate of new visible edges does not show a very clear result, the restoration quality descriptors gives an obvious outcome that Ancuti's technique performed better than the other two techniques in most of the images and Tarel's approach remain last. Table II also describes the performance evaluation of the images of these three approaches [5][7][10] based on reference methods. Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10 and Fig. 11 show the statistical analysis of these reference methods graphically in respect of MSE, PSNR, NCC, AD, SC, MD, and NAE respectively. From these graphs, it can clearly understand that Ancuti et al. [10] method perform better on most of the images from the other approaches. Finally, to evaluate the real-time efficiency of the three fog removal approaches, we made a test applying on images of size 200*200.

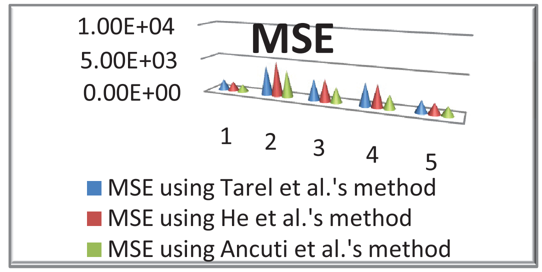


Fig. 5. Mean Square Error (MSE) Comparison

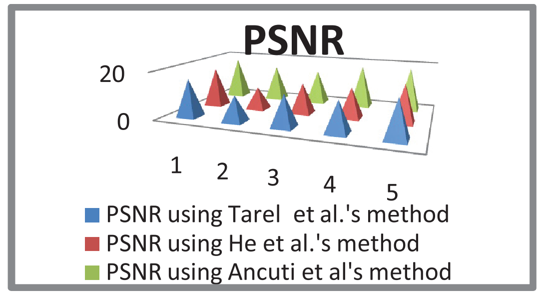


Fig. 6. Peak Signal to Noise Ratio (PSNR) Comparison

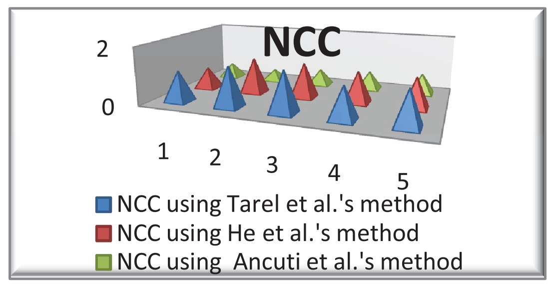


Fig. 7. Normalized Cross Correlation (NCC) Comparison

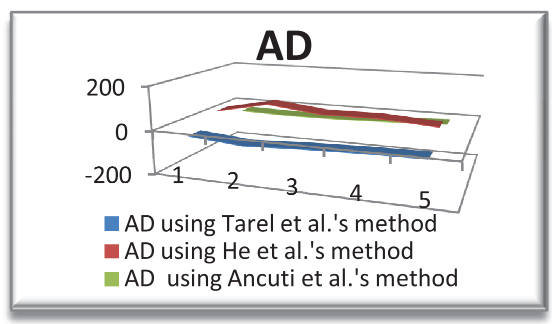


Fig. 8. Average Difference (AD) Comparison

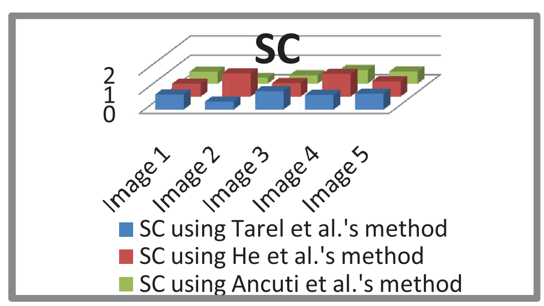


Fig. 9. Structural Content (SC) Comparison

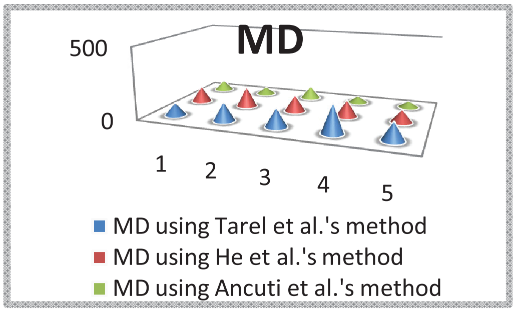


Fig. 10. Maximum Difference (MD) Comparison

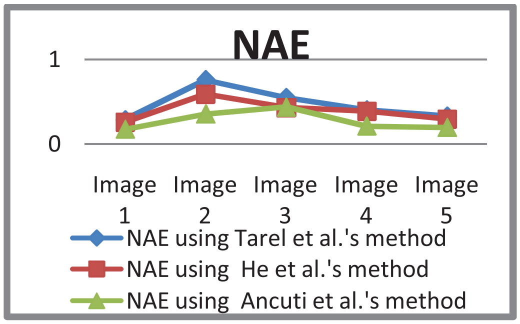


Fig. 11. Normalized Absolute Error (NAE) Comparison

C. *Algorithms Efficiency Comparison*

As a final performance evaluation, we recorded the processing time of each algorithm, and it has been depicted in Table III. It is quite clear that Ancuti et al.'s [10] approach has a significantly faster speed than the others. Furthermore, Tarel et al.'s[5] technique takes a much longer time to compute compared to He et al.'s[7] technique. For estimating the real-time performance of three fog removal algorithms, we made a test applying on images of size 200*200.

TABLE III. COMPUTATION TIME(S) OF THREE ALGORITHMS

Processing time for all images(seconds)			
Image	***Tarel et al.[5]***	***He et al.[7]***	***Ancuti et al.[10]***
Image 1	0.4633	0.7158	0.3354
Image 2	0.7752	0.9636	0.5186
Image 3	0.5534	0.7754	0.3934
Image 4	0.6652	0.8446	0.4126
Image 5	0.4534	0.6724	0.2933

Note: above algorithms are tested on Win 7, and the software is Matlab 2015a. The hardware is Intel Core-i7 and 8 GB RAM.

VI CONCLUSION

The problem of degradation in outdoor images because of poor atmospheric environment is a serious issue in computer vision-based applications. Images acquired by a visual system are severely degraded under the hazy and foggy weather, which will affect several computer vision based applications. Therefore, restoring the degraded image to its clear form is of great significance. The paper investigated many approaches about image dehazing algorithms. Three well-known algorithms are also implemented, and a comparative analysis is also being done. Finally, to evaluate the effectiveness of the methods used, different qualitative assessment evaluation is performed which is the contributory step of this paper. Experimental results demonstrate that the used methods show good results for fog degraded visual images and these results open the track for the use of this algorithm in advanced driver assistance system, vehicle navigation, and traffic monitoring in bad weather condition especially arise due to fog. It is our hope that the comparative study and performance evaluation of fog removal algorithms presented in this paper can be a useful contribution to the development of new and better fog removal algorithms.

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REFERENCES

[1] S.G. Narasimhan and S.K. Nayar, "Interactive (de)weathering of an image using physical models," Proc. Workshop Color Photometric Methods ICCV, pp. 1387–1394, Oct. 2003.

[2] Y. Zhai and X. Liu, "An Improved Fog-degraded Image Enhancement Algorithm," Proc. IEEE Conf. on Wavelet Analysis and Pattern Recognition, Beijing, China,2-4 Nov. 2007.

[3] Y. Y. Schechner, S.G. Narasimhan and S.K. Nayar, "Instant Dehazing of Images Using Polarization," Proc. IEEE Int. Conf on Computer Vision and Pattern Recognition, Vol. 1, pp. 325-332, 2001.

[4] R. T. Tan, "Visibility in bad weather from a single image," Proc. IEEE Conf. Comput. Vis. Pattern Recognit., pp. 1–8, Jun. 2008.

[5] J.-P. Tarel and N. Hautiere, "Fast visibility restoration from a single color or gray level image," Proc. IEEE Int. Conf. on Computer Vision, pp. 2201–2208, Sep.–Oct. 2009.

[6] J. Li, Y. Wang, H.Sun, R. Tian, and Y. Zhang, "Restoration of an atmospherically blurred image based on physical model fusion approach," IEEE Conf., 2010.

[7] K. He, J. Sun, and X. Tang, "Single image haze removal using dark channel prior," Proc. IEEE Conf. Comput. Vis. Pattern Recognit., pp. 1956–1963, Jun. 2009.

[8] I. Enesi and R. Miho, "A Fast Algorithm For Contrast Restoration Of Weather Degraded Images," 6th IEEE Int. Conf. on Complex, Intelligent, and Software Intensive Systems, 2012.

[9] A.K.Tripathi and S. Mukhopadhyay, " Single Image Fog Removal Using Bilateral Filter," IEEE Conf., 2012.

[10] C. O. Ancuti and C. Ancuti, "Single Image Dehazing by Multi-Scale Fusion," IEEE Trans. on Image Processing, Vol. 22, No. 8, August 2013.

[11] T. Pal, M. K. Bhowmik, and A.K Ghosh, "Contrast Restoration of Fog-Degraded Image Sequences," Proc. Springer Int. Conf. on Soft Computing for Problem Solving, Vol.335, pp. 325-338, 2014.

[12] T. Pal, M. K. Bhowmik, and A.K Ghosh,"Defogging of Visual Images Using SAMEER-TU Database," Proc. Elsevier Int. Conf. on Information and Communication Technologies, 3-5 December 2014.

[13] N. Hautiere, J.-P. Tarel, D. Aubert, and E. Dumont, "Blind contrast enhancement assessment by gradient ratioing at visible edges", J. Image Anal. Stereol., vol. 27, no. 2, pp. 87–95, 2008.

[14] M. Kutter and F. A. P. Petitcolas, "A fair benchmark for image watermarking systems," Proc. SPIE Int. on Conf. Security and Multimedia Contents, pp. 226-239, 1999.

[15] R. Sakuldee, and S. Udomhunsakul, "Objective Performance of Compressed Image Quality Assessments," Int. J. of Computer, Electrical, Automation, Control and Information Engineering Vol:1, No:11, 2007.