Comparative Re-evaluation of Different Single Image Defogging Techniques: A Review

Asifa Baba, Md. Imtiyaz Anwar, A. H. Moon, and Arun Khosla

Abstract Image defogging has turned out to be a demanding task nowadays and to propose several assumptions and approaches for the visibility enhancement of the imagery under consideration, is a need for an hour. Poor weather conditions degrade the image contrast resulting in image blurring and pixel distortion and are thus responsible for the road accidents occurring in the world. For several other applications like remote sensing, video surveillance, navigation, etc., clear and high-quality images are needed. The main objective of the paper is to contemplate the existing state-of-the-art techniques for image defogging for the visibility improvement. Finally, the paper is concluded with the current status of image defogging techniques, their comparative results, and delivers insightful discussions and prospects for future work to boost the efficiency and accurateness of existing systems.

Keywords Computer vision · Image fusion · Fog removal · Performance evaluation · Deep learning

1 Introduction

In most of the image processing applications, limited visibility in foggy environment has been a severe concern. Consequently, under foggy circumstances, the imagery

A. Baba (✉) · A. H. Moon
Islamic University of Science and Technology, Awantipora, Kashmir, India
e-mail: asifa.baba@islamicuniversity.edu.in

A. H. Moon
e-mail: ayaz.moon@islamicuniversity.edu.in

Md. Imtiyaz Anwar
Babasaheb Bhimrao Ambedkar University, Bihar, India
e-mail: imtiyaz.ece@gmail.com

A. Khosla
NIT, Jalandhar, Punjab, India
e-mail: khoslaak@nitj.ac.in

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acquired by the camera loses their contrast and colour fidelity. In foggy environments, there exist numerous atmospheric particles of considerable size. These particles not only take in and disperse the reflected light of the scene but also disseminate a portion of atmospheric light to the camera. Therefore, the image captured has poor visibility and decreased contrast influencing badly the visible light optical system. This leads to the difficulty in detection of objects under observation and leads to increase in accidents on road. The degradation in visibility is mostly affected by fog during winters in north India and other similar regions of the world. It has been estimated that more than two million people die per year of car accidents across the world, out of which 24% of all such accidents are due to bad weather [1]. In December 2018, eight people including seven from the same family died of road accident in a highway pile-up due to heavy fog in Haryana, India. Immediately on December 29, 2018, seven people were killed and four injured due to heavy fog on Ambala-Chandigarh National Highway, Haryana, India. As per the data given by the Ministry of Road Transport and Highways (MORTH) [2], the number of accidents in India due to foggy weather in years 2016, 2017 and 2018 increased drastically and is shown by the bar graph (Fig. 1).

Therefore, there is a need for an efficient image defogging algorithm to increase the perceptibility and the contrast of the captured degraded image. The images captured are of different types like visible, infrared, computed tomography (CT) images and magnetic resonance images (MRI). In order to defog the image captured by the camera, several visible image defogging techniques are implemented by different researchers. The evaluation of such existing state-of-the-art techniques is contemplated in this paper.

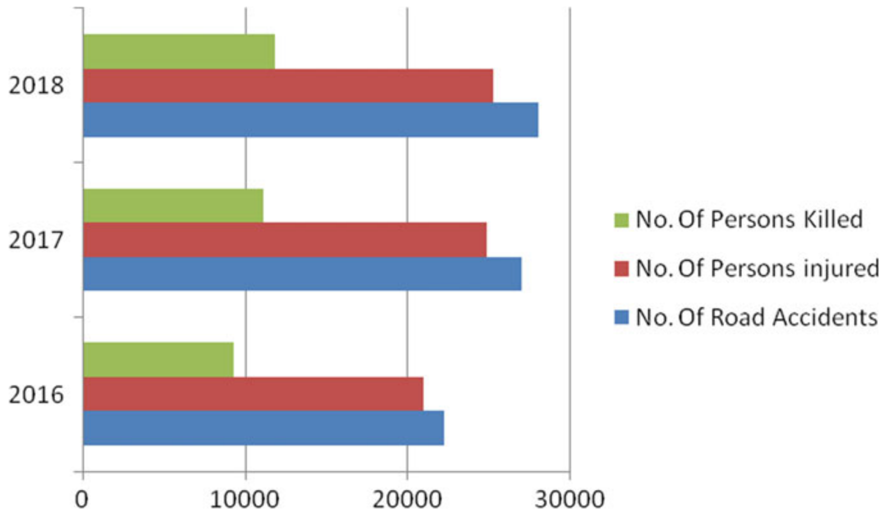

Fig. 1 Number of accidents due to foggy weather in India from 2016 to 2018

2 Review of Contemporary Techniques

The significant work has been done by the researchers in the area of image defogging in order to increase the contrast and colour fidelity of imagery, but the methods in use still struggle with several limitations and improving visibility is an inevitable task to be done. In this section, various visual-, infrared- and fusion-based image defogging techniques have been comprehensively investigated, and their limitations are discussed.

Most of the non-sky patches of haze-free outdoor images include pixels having very low intensities in at least one colour channel. Subsequently, a dark channel prior method has been employed by the researchers in [3] for effective dehazing of a single image to remove the low-intensity information elements. In the proposed technique, the image is more refined by the process of matting in order to reduce the blocking artifacts. The only disadvantage with this algorithm is that the defogging scheme proved to be inefficient for the images containing large sky regions because the colour of the sky is very similar to the atmospheric light in the hazy image.

A visual image defogging scheme has been put forward in [4] in which the visibility of the captured scene in an intense foggy state has been improved. The proposed method has been accomplished by using the methods of contrast enhancement operation, luminance weight map and chromatic weight map followed by the multiscale fusion to get the fog-free images. In order to test the proposed algorithm, large set of images is created by the authors named as SAMEER-TU database to study the effect of variability of emerged scenes. However, under decreased illumination conditions, foggy images still suffer from low visibility.

Authors in [5] have set forth a novel single image fog removal technique for greyscale and RGB images, introducing dark channel prior (DCP) followed by weighted least square (WLS) and high dynamic range (HDR) for the improvement of the visibility of an image in terms of contrast adjustment and preservation of edges without employing any pre-processing steps. However, the proposed technique due to the image conversion to HDR shows minor saturation in few images. Moreover, said proposed scheme is used for the enhancement of the images containing the small sky regions only.

In [6], authors have presented a novel method of fusing visible and infrared images using latent low-rank representation (LatLRR) for visibility enhancement. In this proposed technique, both infrared and visible images are decomposed into two scale representations to generate the low-rank parts and the saliency parts for each source image using LatLRR. In order to reduce the image artefacts, a guided filter is then used on the saliency part, thereby making complete use of spatial reliability. Later, a fusion global-local-topology particle swarm optimization (FGLT-PSO) is used to construct adaptive weights of the low-rank parts in order to get more information from visible and infrared images. The resultant image is recovered back by summing up the low-rank and the fused saliency parts of an image. The said proposed method outperforms several existing fusion methods; however, it is slow in speed and takes much execution time with the increase in the number of iterations.

A novel technique to enhance the contrast of foggy images using contrast limited adaptive histogram equalization (CLAHE) algorithm has been presented in [7]. CLAHE disintegrates the whole image into well-defined regions irrespective of taking the whole image into consideration as in histogram equalization, by determining the number of histograms corresponding to each data region. In this defogging scheme, the RGB image on the one hand is decomposed into red, green and blue components and a CLAHE algorithm is applied to R component of the RGB image and then the CLAHE transformed R component is merged with G and B component of the RGB channel. On the other hand, the same source image is decomposed into HSV components and to S and V components and CLAHE algorithm is applied which are finally merged with the H component of an image. The two resultant images are fused together to get the enhanced image. The proposed system proved to be superior than existing state-of-the-art methods like histogram equalization, adaptive histogram equalization, etc, however the method employed is slower than existing schemes as the CLAHE operates on small distinct image regions rather than the whole image.

An adaptive hybrid image defogging (AHID) algorithm has been presented by the author in [8] for the enhancement of foggy images employing the use of multilevel fusion based on weight maps after enhancing the lighter and darker regions independently. The dark channel prior (DCP) algorithm is employed to approximate the amount of fog present in the image and the fusion-based defogging algorithm is used to remove the remaining image artefacts present in the foggy image. Later, the edges of the resultant image are enhanced using unsharp masking for improved results. Fog removal by the proposed technique is beneficial compared to other conventional methods only when the nearby foggy images are considered; however, the far off object to be enhanced introduces some blurring effects and colouring artefacts in the reconstructed image.

A novel fast algorithm for defogging the single image has been presented in [9] where an RGB image is transformed into HSI form which is later on divided into a plurality of blocks. The maximum point from the S component in each block is selected, and at the same time, I component of HSI image is adjusting so that the fog component is estimated through bilinear interpolation. The fog component thus obtained can be subtracted from the RGB values of each block of an image to be defogged, and the resultant image is enhanced by adjusting the brightness of an image to get the defogged image. The proposed algorithm is simple, easy to implement and showed improved image visibility compared to conventional algorithms. Moreover, the sky regions are dealt individually for the enhancement purpose. However, since the defogging operation is implemented on block level, the technique is slow and takes much execution time.

Employing dark channel prior (DCP) methods for the visibility improvement has a drawback of overestimating the haze from its actual value in case of images containing bright white objects, leads to the distorted image at the output. So, In order to get the reconstructed image with decreased colour distortion researchers in [10] has come up with the image defogging model integrating saliency detection with dark channel prior. The technique of saliency detection method is based on the contrast of superpixel intensities and is used to get the saliency feature out of the foggy image. These saliency features of the dark channel image, excluded from bright white objects, are used to approximate the transmission and atmospheric light. In order to recover the scene radiance, self-adaptive upper bound is fixed to avoid few regions to be too bright. Since author has used the DCP at its initial stage therefore the proposed algorithm is simple and effective. However, the approach employed in [10] is not used to recover the degraded colour components in the image and hence shows a slight distortion in the reconstructed image.

Authors in [11] employ the technique of depth estimation, colour analysis and a visibility restoration for improving the poor visibility of images collected in calamitous weather. The satisfactory results of median filter technique and an adaptive gamma correction method have been exploited in the proposed depth estimation module for the restoration of images with complicated structure. The transmission map estimation can be adjusted to decrease the halo effects present in the captured image. The colour analysis module has been used to analyse the coloured features of the raw hazy image followed by the visibility restoration block that uses both the transmission map and the colour correlation information to repair the distortion in colour at the end. This technique is used to reduce the atmospheric effects seen in the foggy image with complicated structures, and hence, proficient transmission map estimation can be estimated. The limitation of using median filtering is that the images having small signal-to-noise ratio produce false noise edges by breaking down the edges. Moreover, median filtering cannot curb Gaussian noise distributions.

In [12], a novel image restoration method based on contrast limited adaptive histogram equalization (CLAHE) and no-black pixel constraint with planar assumption (NBPC + PA) methods has been proposed for visibility enhancement. By employing the cascade scheme, the limitations of CLAHE like distorted edges, degradation in colour and halo effects can be abridged. The two approaches together can enhance the visibility and hence offer better results for homogenous as well as inhomogeneous fog. However, due to these cascaded stages, colour saturation has been seen in the output image and hence leads to image artefacts.

In order to obtain the images with high visibility, authors in [13] proposed a restoration technique based on fusion strategy for defogging. Two-derived images have been obtained by the contrast-based method and statistical-based approach, respectively, and are weighted by a specific weight map in order to restore the image back. Compared to other conventional methods, the fusion strategy-based method discussed above proved to be simpler and shows slightly better results. The only limitation of such fusion-based methods is the objectionable visible image artefacts observed due to contrast-based restoration methods employed in the proposed technique.

In [14], a technique of image defogging has been put forth by the authors in which a multilevel perceptron has been used to find out the transmission map directly from the image. Further, dynamic range has also been increased by different contrast stretching methods in order to increase the SSIM index and hence the peak signal-to-noise ratio. However, since the proposed technique is trained on 80 different images, it increases the computational time for the execution of code.

A simpler yet effective method of image defogging has been presented by the authors in [15] involving the process of Retinex algorithm and wavelet transform method, thereby enhancing the boundary information and the high-frequency details of a foggy image. However, the discrete wavelet transform introduces the blocking artefacts in the reconstructed image.

Organization of the paper is as follows. In Sect. 2, review of various contemporary image defogging techniques and their limitations are discussed. Section 3 shows their comparative study in tabular form. Section 4 shows the qualitative and quantitative results of some of the designed algorithms discussed in literature survey, followed by the last section which elucidates the conclusion and future scope of the image defogging techniques.

The contribution of the research conducted by various authors with the limitations found so far in the field of image defogging has been tabulated below (Table 1).

3 Comparative Results and Analysis

In this section, few methods given by the researchers discussed in the literature survey have been evaluated on several test images, and their quality parameters have been calculated and compared for the qualitative and quantitative appraisal. Figure 2 depicts the resultant defogged image obtained using algorithms designed in [3, 14, 15] by the authors, and Fig. 3a, b, c shows the quality parameters like standard deviation, SSIM index and entropy of the defogged images.

4 Conclusion and Future Scope

In this paper, several image defogging techniques for visibility improvement, put forth by researchers in order to evaluate the performance, have been summarized. Despite the considerable progress achieved in such defogging techniques as discussed earlier, a number of limitations have been observed in one way or the other. There also exist several kinds of environmental variations that make the existing techniques more difficult to implement. Therefore, an efficient algorithm is compulsory to muddle through several challenges arising from the nature of visibility enhancement of foggy images. Further, strategy to investigate the research to be carried out includes the use of fusion-based methods for increasing the visibility of the foggy image due to the number of complimentary characteristics of visual and thermal images. There is an enormous scope in this field for further enhancements of foggy images by incorporating the deep learning artificial neural networks especially convolution neural networks (CNN) because of its advantages like maximum utilization of unstructured data, elimination of unnecessary cost and ability to produce high-quality results. Moreover, the performance of different existing techniques may be

Table 1 Summary of comparative findings

Author	Defogging techniques employed	Outcome	Limitations
He et al. [3]	Proposed a simple yet effective single image haze removal technique using dark channel prior followed by the soft matting procedure to refine the transmission by reducing blocking artefacts in an image	• Recovery of high-quality haze-free image containing non-sky regions • Easy algorithm to put into operation	• Proved inefficient for the images containing sky regions
Huang et al. [11]	Presented the technique for visibility improvement utilizing the technique of depth estimation, colour analysis and visibility restoration	• Decrease in halo effects observed in foggy image • Effective map transmission can be achieved • Reduction in colour distortion	• Results in edge breaking • Cannot curb Gaussian noise distributions
Pal et al. [4]	Designed a novel image defogging scheme for the enhancement of dense foggy imagery using SAMEER-TU database	• Easy and simple algorithm used hence incorporates less computing transparency	• Fails to improve the contrast of foggy images captured in a very low illumination state
Thulasika et al. [13]	An image fusion-based strategy has been employed based on contrast enhancement and statistical approach	• Easy to implement due to simple algorithm • Provide better PSNR compared to other state-of-the-art techniques	• Unpleasant image artefacts can be seen in contrast-based restoration methods
Wang et al. [9]	The proposed defogging technique is based on the colour space of HSI. Fragmentation and bilinear interpolation has been employed for effective image defogging	• Improved image visibility than conventional methods • Deals with the sky regions individually • Algorithm is easy and simple	• Because of block level operation, the proposed technique is slow and takes much execution time

(continued)

Table 1 (continued)

Author	Defogging techniques employed	Outcome	Limitations
Anwar et al. [5]	Employs fog removal technique based on dark channel prior, weighted least square and high dynamic range	• Proposed technique proved efficient in preserving sharp details • Maintains the colour quality of the reconstructed image	• Due to the conversion from RGB to HDR, oversaturation in few images has been seen • Suitable for defogging the images with small sky regions
Surekha and Naveen Kumar [15]	Authors presented a novel image defogging technique involving the process of Retinex algorithm and wavelet transform method, thereby enhancing the boundary information and the high-frequency details of a foggy image	• Simpler algorithm used to implement the proposed defogging technique	• DWT leads to artefacts in the output image
Salazar et al. [14]	An image defogging has been presented using multilevel perceptron, thereby increasing the PSNR and SSIM index	• Provides superior performance in terms of SSIM index and PSNR	• More computational time required
Zhang et al. [10]	Designed an image dehazing algorithm by combining saliency features with dark channel prior to get the fog-free image with less colour distortion	• Simple and effective algorithm	• Slight colour distortion in defogged image • Degraded components in an image cannot be improved
Kumar et al. [7]	Proposed image defogging technique based on contrast limited adaptive histogram equalization (CLAHE) algorithm	• Proved superior than existing state-of-the-art methods	• Produced colour and edge distortion, boosts noise and creates halo effects • Slower than existing schemes as it operates on small data regions

(continued)

Table 1 (continued)

Author	Defogging techniques employed	Outcome	Limitations
Han et al. [6]	Put forth a fusion-based adaptive multi-defogging method for improving the visibility	• Better performance than other existing fusion-based methods in terms of evaluation parameters	• Execution time increases with the increase in number of iterations
Hassan et al. [12]	Put forth a cascaded technique employing contrast limited adaptive histogram equalization (CLAHE) and no-black pixel constraint with planar assumption (NBPC + PA) for improving the visibility of foggy image	• Improved performance in terms of visibility enhancement	• Image artefacts observed in restored image
Krishnan et al. 2019 [8]	Presented an adaptive hybrid image defogging (AHID) algorithm using multilevel fusion technique	• Efficient in removing the image artefacts • Better quality of defogging image in terms of PSNR	• Blurring effects and colouring artefacts seen for the far off objects in the foggy image

conducted and compared with existing systems, thus avoiding the chances of road accidents due to bad weather and hence increases the visibility.

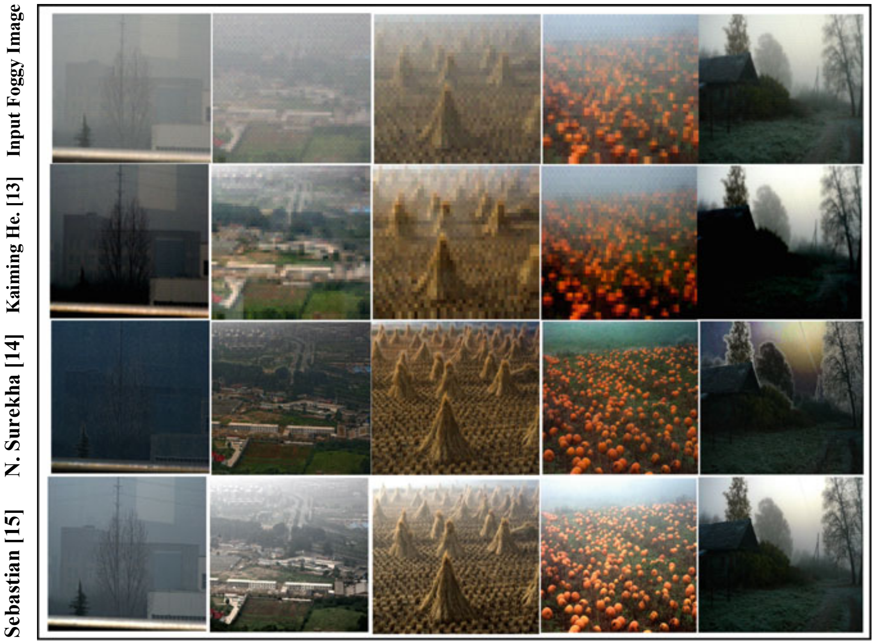

Fig. 2 Performance of defogging algorithms presented in [3, 14, 15] on five different images. From left to right: Scene1, Canon, Cones, Pumpkin, Scene2

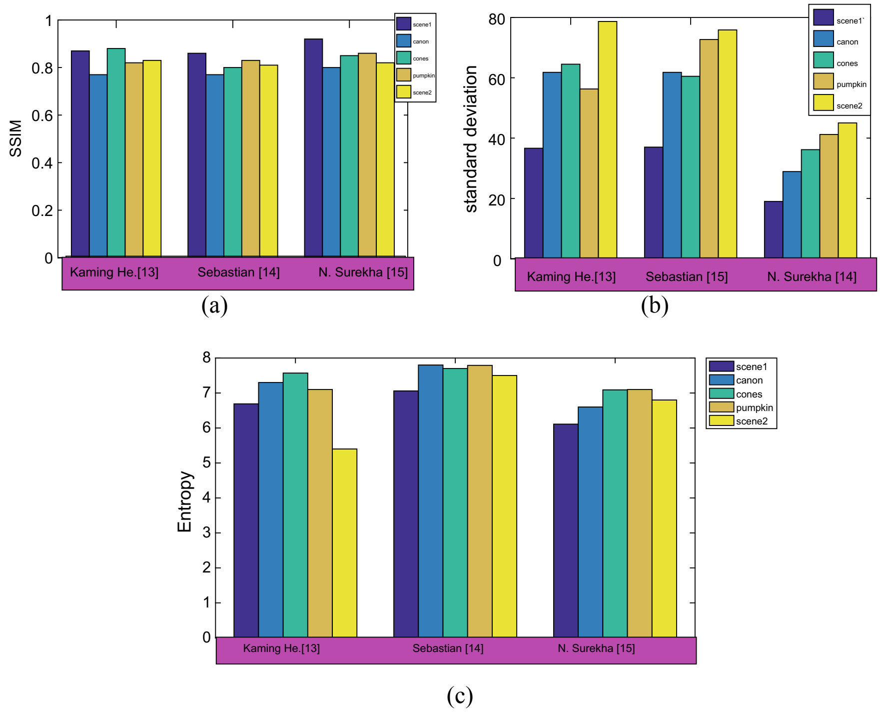

Fig. 3 **a**, **b**, **c** Comparisons of the value of standard deviation, SSIM index and entropy on several test images by the methods employed in [3, 14, 15]

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