Contrast Restoration of Fog-Degraded Image Sequences

Tannistha Pal, Mrinal Kanti Bhowmik and Anjan Kumar Ghosh

Abstract Poor visibility in the presence of fog is a major problem for many applications of computer vision. Still image and video systems are typically of limited use in poor visibility condition as the degraded images/frames lack visual vividness and offer low visibility of the scene contents. This paper investigates the defogging effects on images and frames by using a fast defogging method on our own newly developed database, namely Society of Applied Microwave Electronics Engineering and Research-Tripura University (SAMEER-TU) database which consists of 5,390 color images and 10 videos captured in foggy as well as in clear condition. The first step of the method ensures contrast enhancement yielding better global visibility, but the images/frames containing very dense fog still suffer from low visibility. In that case, Luminance and chromatic weight map have been used. Finally for verifying the robustness of the method, qualitative assessment evaluation in respect of peak-signal-to-noise ratio (PSNR) and root-mean-square error (RMSE) is introduced as a contributory step in this paper.

Keywords SAMEER-TU database · Defogging of images and frames · Contrast enhancement · Luminance weight map · Chromatic weight map · Qualitative assessment evaluation

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1 Introduction

Poor visibility in bad weather condition is the main challenge of computer vision applications, mainly caused by atmospheric aerosols, such as fog, haze, and rain. Most computer vision applications such as video surveillance, remote sensing, and intelligent vehicles assume that the input images/frames should have clear visibility. However, due to bad weather condition, images and video lose the contrast and color fidelity, and those reduce the effectiveness of human visual system. Generally, the effect of computer vision applications is limited by heavy fog that degrades the contrast information of the scene and significantly reduces the visibility of the image/frame [1, 2], and therefore, improving visibility is an inevitable task. However, standard filtering does not restore these low contrast images/frames [3].

Many research works have been done using contrast enhancement techniques to restore contrast of weather-degraded images/frames [1, 3, 4], which do not need any scene depth information and avoid complicated atmospheric scattering model. He et al. [5] proposed a simple but effective image dark channel prior to remove haze from a single image. Tarel and Hautiere [6] developed a contrast enhancement assessment method which is based on computing the ratio between the gradients of the visible edges in the image before and after visibility enhancement. Tan [7] presented an algorithm for restoring contrast from a single input image by maximizing the contrast of the direct transmission while assuming a smooth layer of air light. Zhu et al. [1] proposed an image clearness technique for fog by using a moving mask-based sub-block overlapped histogram equalization method. In a very recent work, Ancuti and Ancuti [8] proposed an effective method to remove the effects of fog from a single image using a fusion-based strategy based on a single degraded image. This method performs in a per-pixel fashion, which is straightforward to implement.

This paper presents a newly created database, namely Society of Applied Microwave Electronics Engineering and Research-Tripura University (SAMEER–TU) database in an outdoor environment containing natural scene images and videos captured by both NIKON D5100 Visual Camera and FLIR E60 Thermal Camera. Total of 5,640 visual images have been captured by Nikon D5100 in foggy, poor illumination, and normal conditions, and 120 images of visual and its corresponding thermal images have been captured by FLIR E60 in the same conditions. Based on the visibility parameter and other ground truth information obtained per hour from the meteorological department [9, 10], the weather condition is categorized as foggy, poor illumination and normal conditions. Total of 5 thermal videos are taken where the duration of the video is 90 min, and 10 visual videos are taken whose duration is 179 min 50 s. This paper also describes a method for enhancing the visibility of visual degraded images and videos in dense foggy condition by using contrast enhancement operation, luminance weight map, and chromatic weight map followed by multiscale fusion. In order to verify the robustness of the method, qualitative assessment evaluation is introduced as a contributory step of this paper. In this paper, only foggy images and the same images captured in normal condition have been taken from SAMEER-TU database for implementation purpose and for qualitative assessment evaluation.

The rest of this paper is organized as follows. Section 2 presents the creation of our own developed SAMEER-TU database, Sect. 3 describes a method for enhancing the visibility of fog-degraded images/videos, Sect. 4 deals with Experimental Results and Discussion along with Qualitative Assessment Evaluation, and Sect. 5 concludes this work.

2 Creation of SAMEER-TU Database

2.1 Design and Development of SAMEER-TU Database

This paper briefs the creation of a database consisting of natural scenes in outdoor uncontrolled condition, which is being created in the Biometrics Laboratory of Department of Computer Science and Engineering of Tripura University (TU), India. In this database, total 5,640 visual images and 10 videos are captured by visual camera NIKON D5100. Out of 5,640 images, 1,020 images are captured in foggy condition, 250 images in poor illumination condition, and 4,370 images in normal condition. Sometimes images captured in dense fog in poor illumination condition by visual camera lose the total contrast and color fidelity, and it is very difficult to improve the visibility of the image. So a database is also being created consisting of visual and its corresponding thermal images, captured by thermal camera, i.e., FLIR E60 to fuse both thermal and its corresponding visual images/frames to enhance the visibility of the fog-degraded images. Some sample images of natural scenes captured by NIKON D5100 visual camera and FLIR E60 thermal camera are shown in Figs. 1 and 2, respectively.

This paper mainly focuses on contrast enhancement method for improving the visibility of visual fog-degraded images and frames. So only foggy images and the same images captured in normal condition have been used from SAMEER-TU database to test the algorithm and for qualitative assessment purpose, respectively.

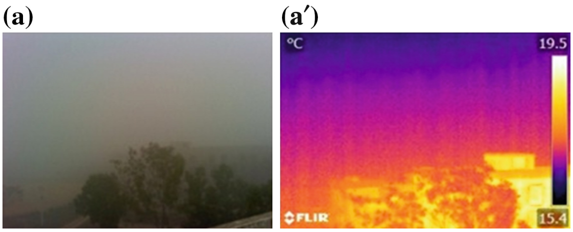


Fig. 1 **a** Foggy visual image. **a′** Corresponding thermal image

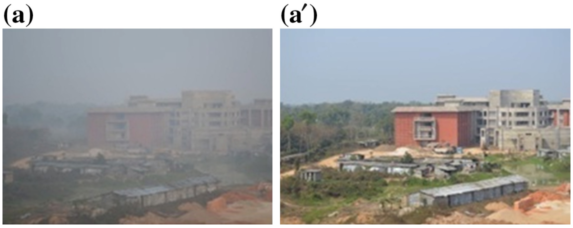


Fig. 2 **a** Foggy visual image. **a′** Corresponding clear/normal visual image

2.2 Designing of Natural Scene Database in Foggy Weather Condition

The SAMEER-TU database consists of 5,390 natural scene visual images captured in foggy and normal/clear conditions which can be useful for the researchers for the development and testing of new algorithms and also for comparative evaluations of different systems.

Equipment Setup for Image Capturing Nikon D5100 cameras with Nikon 18–55-mm lens, shutter speed 1/125–1/200, apertures f/5.6–f/8 are used for capturing the images. All natural scene images and videos are captured in an outdoor environment in foggy and normal conditions from the month of January to March of the year 2014.

Image Capturing Conditions Images in an outdoor environment are mainly influenced by weather effects such as fog, haze, and rain which results in poor visibility of the image. In this database, images have been captured in foggy and normal conditions. Foggy condition usually occurs when the difference between normal temperature and dew point is less than 2.5 °C, relative humidity remains nearly 100 % and visibility remains less than 1 km [11, 12]. Clear condition is generally considered when the visibility remains 3 km [13]. While capturing those images, the temperature normally ranges from 5 to 20 °C, humidity ranges from 95 to 100 %, dew point ranges from 5 to 15 °C, wind speed ranges from 1 to 3.5 mph, and visibility ranges from 0 to 3 km [9, 10]. Each image is attached with useful ground truth information such as visibility, temperature, humidity, wind speed, and dew point temperature.

Naming Convention The SAMEER-TU database contains high-quality color visual images (3,696 × 2,448 pixels, 24 bits per pixel) of outdoor natural scenes captured after every 15 min from 6 a.m. to 6 p.m. After capturing, all the images have been renamed for ease of understanding. To make the naming convention meaningful, different codes have been used for different natural scenes in different days. The naming code of the image is as follows: Day Number_Natural Scene Number_Outdoor Condition, for example, image name D1_NS1_OD[6.00a.m]_I(1).jpg indicates that the image is taken in Day 1 (6.02.14) of Natural Scene 1 which have been captured in an outdoor environment at 6.00 a.m. with image sequence no. 1.

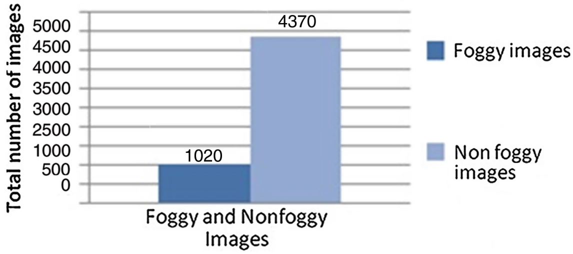


Fig. 3 Distribution of foggy and nonfoggy images

Statistical Analysis of Natural Scenes in Foggy and Nonfoggy Conditions Based on visibility parameter obtained per hour from meteorological department [9, 10], images have been classified as foggy and nonfoggy images. Foggy images or videos are considered when the visibility remains less than 1 km [11, 12], while the clear image is normally considered when visibility remains 3 km [13]. These foggy and nonfoggy images or videos are useful to verify the robustness of the algorithm used in this paper. The distribution of foggy and nonfoggy images is shown in Fig. 3.

3 Enhancement of the Fog-Degraded Image Sequences in Poor Visibility Condition

This paper implements a technique for enhancing the fog-degraded visual image and frames of video [8] along with qualitative assessment evaluation. Figure 4 presents the system flow of the technique.

3.1 *Step 1: Derived Input to Improve the Contrast in Fog-Degraded Image/Frame*

Color cast due to the air light influence and lack of visibility into distant regions due to scattering and attenuation phenomena are the main obstacles for degradation of the image/frame. The derived input from the foggy frame deals with the contrast enhancement that yields a better visibility mainly in the degraded region [8].

The derived input is obtained from the below equation

$$I_2(x) = \gamma(I(x) - \bar{I}) \tag{1}$$

where

$I_2(x)$ is the derived input image/frame

$I(x)$ is the foggy image/frame

$\bar{I}$ is the average luminance value of the foggy image/frame that is found out by averaging the RGB color channels

γ is a factor whose default value is 2.5, and x is the pixel value of the image/frame.

Experimental result of Step 1 is shown in Fig. 6.

Experiments conducted in each step have been performed in MATLAB using graphical user interface (GUI). The experimental result of Step 1 is shown in Fig. 5.

The contrast enhancement operation mentioned in Step 1 increases the contrast of the foggy image/frame. But its limitation lies when images/frames contain dense

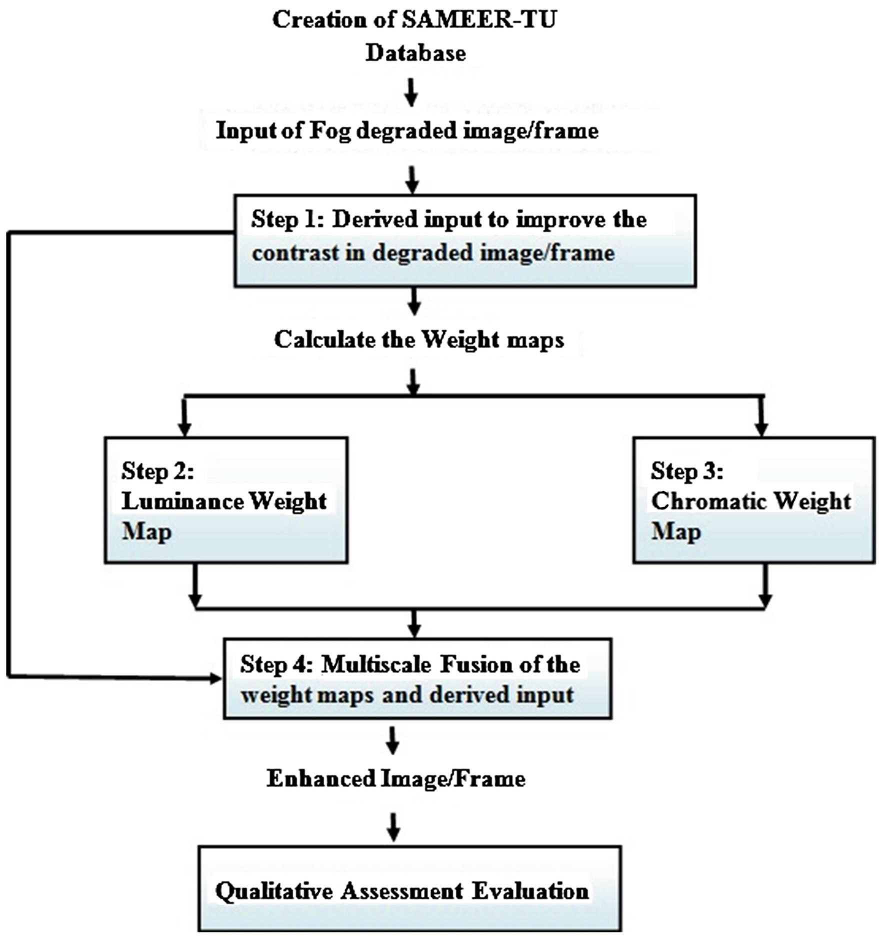


Fig. 4 System flow of the technique

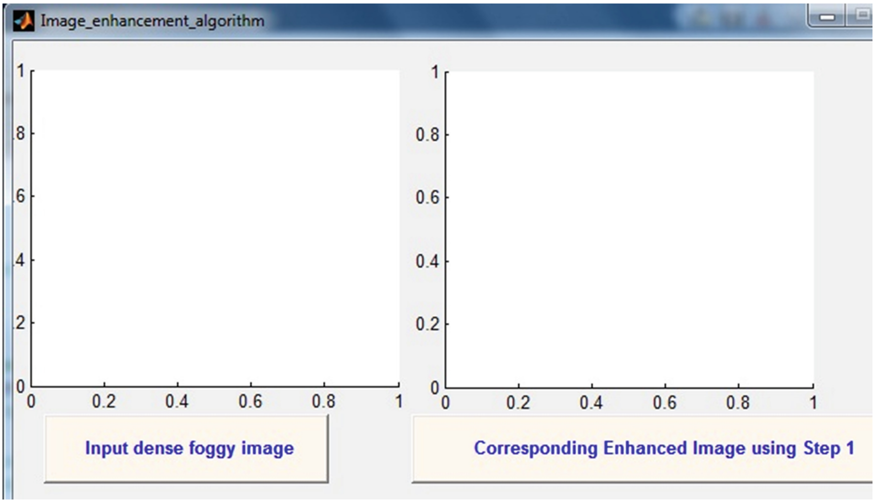


Fig. 5 Load input dense foggy image/frame and its corresponding enhanced image/frame using graphical user interface

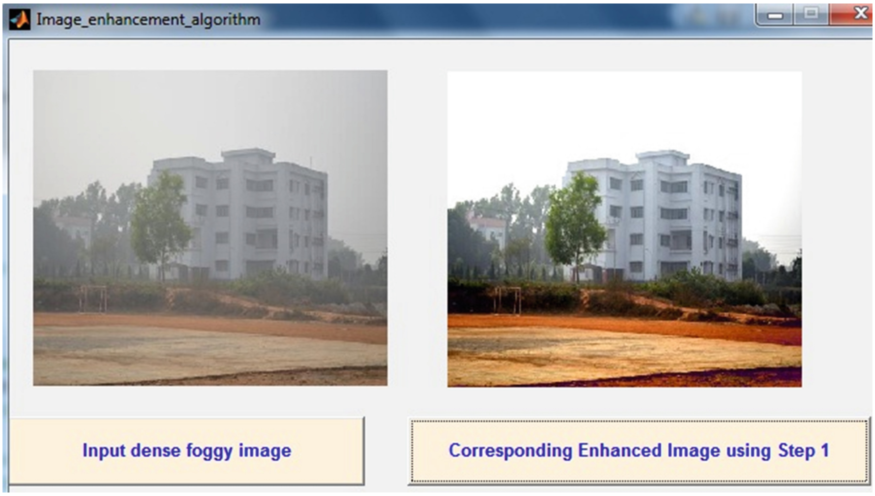


Fig. 6 Corresponding enhanced image/frame of the real-time dense foggy image/frame by using Step 1

fog and suffer from low visibility. For this, luminance weight map and chromatic weight map have been used. Luminance weight map measures the luminance gain of the derived input image/frame and adds brightness to the image/frame while chromatic weight map measures the saturation gain and adds colorfulness to the image/frame.

3.2 Step 2: Luminance Weight Map

The luminance weight map measures the luminance gain of the derived input image/frame. This weight is processed based on the RGB color channel information [8]. The luminance weight map is obtained from the below equation

$$W_L^K = \sqrt{\frac{1}{3}\left[\left(R^k - L^k\right)^2 + \left(G^k - L^k\right)^2 + \left(B^k - L^k\right)^2\right]} \tag{2}$$

where L represents luminance computed by averaging the RGB channels and k indexes the derived input.

Experimental result of Step 2 is shown in Fig. 7.

3.3 Step 3: Chromatic Weight Map

The chromatic weight map controls the saturation gain in the derived input image/frame. This weight map is used because in general images characterized by a high level of saturation are preferable [8]. The chromatic weight map is obtained from the below equation

$$W_c^k(x) = \exp\left(-\frac{\left(S^k(x) - S^k_{\max}\right)^2}{2\sigma^2}\right) \tag{3}$$

$S_k(x)$ is the saturation value given by the equation

$$S_k(x) = 1 - \frac{3}{(R+G+B)}[\min(R, G, B)] \tag{4}$$

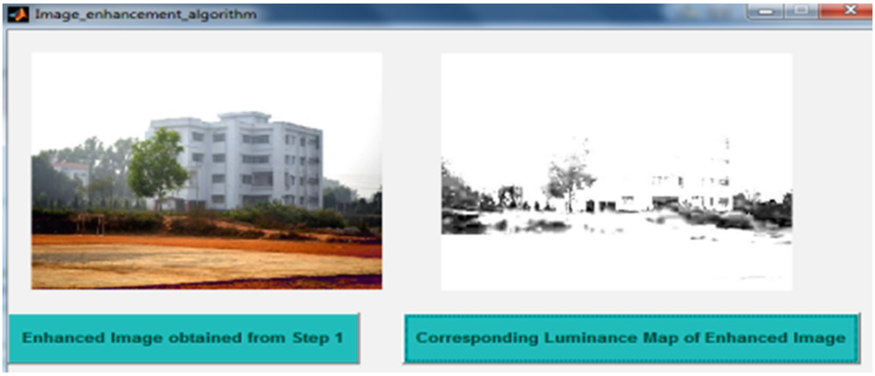


Fig. 7 Corresponding luminance map of enhanced image/frame by using Step 2

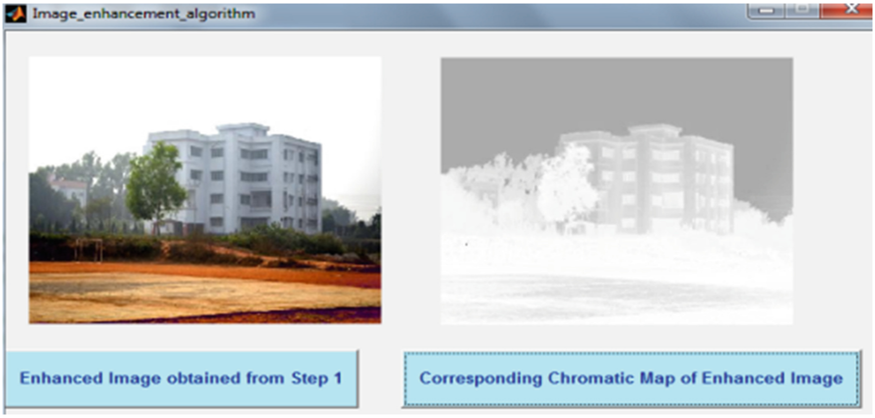


Fig. 8 Corresponding chromatic map of enhanced image/frame by using Step 3

where k indexes the derived input.

$S_{\max}$ is a constant and it depends by the color space employed (for HSI color space $S_{\max} = 1$) and the default value of standard deviation is $\sigma = 0.3$.

Result of Step 3 is shown in Fig. 8.

3.4 Step 4: Multiscale Fusion

In the fusion process, specific weight maps are used in order to conserve the most significant detected features. The resultant weight W_k is obtained by multiplying the luminance weight map and chromatic weight map. To yield a consistent result, normalization of the resultant weight map is done. Each pixel x of the output image F is calculated by summing the inputs I_k weighted by corresponding normalized weight maps $\overline{W}^k$ [8]. The multiscale fusion is obtained from the below equation

$$F(x) = \sum_k \overline{W}^k(x) I_k(x) \tag{5}$$

where I_k symbolizes the input (k is the index of the input) that is weighted by the normalized weight maps. Result of Step 4 is shown in Fig. 9.

4 Results and Discussion

Experiments have been conducted on 120 outdoor real natural scene images taken in dense foggy condition. Due to the scattering of aerosol particles in foggy condition, the scene loses the contrast and color fidelity and thereby reducing the

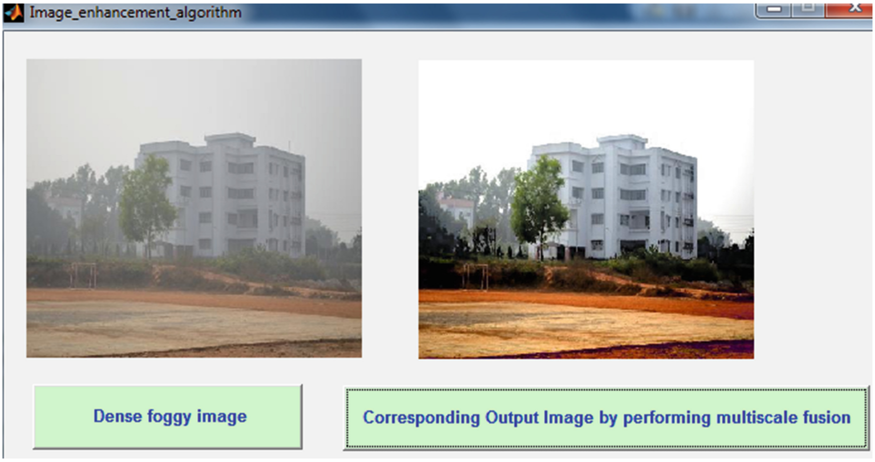


Fig. 9 Fog-free output image/frame by performing multiscale fusion

visibility [14]. Therefore, image enhancement algorithm described previously on Sect. 3 is applied on the dense foggy static images from SAMEER-TU database to restore the contrast. It is observed that by using the first step of contrast enhancement operation of the proposed method, the contrast gets increased in the foggy images and thereby increasing the visibility of the images. But the images containing dense fog still suffer from low visibility. To overcome this limitation, luminance weight map and chromatic weight map are used in a per-pixel fashion to enhance the visibility of the dense foggy images. Luminance weight map measures the luminance gain of the input image and adds brightness to the image while chromatic weight map measures the saturation gain and adds colorfulness to the image. Finally, a multiscale fusion is carried out with contrast enhancement operation and weight maps to enhance the visibility of the image in dense fog. Experimental result reveals that the proposed technique works well on dense foggy static images which have been shown in Fig. 9.

The same technique is also been implemented on the frames of 5 foggy videos from SAMEER-TU database. Experimental result reveals that the technique mentioned in Sect. 3 achieves good defogging effect on large number of dense foggy videos by increasing the visibility. Results of experiments on fog-degraded frames and videos are shown in Table 1 and Fig. 10, respectively.

The next phase of the experiment illustrates a qualitative assessment evaluation on the dense foggy images or frames to test the robustness of our method. The qualitative assessment evaluation is performed based on peak-signal-to-noise ratio (PSNR) and root-mean-square error (RMSE).

Table 1 Experimental result on fog-degraded frames

<table>
<tr><td rowspan="4">Total 3 no of sample frames are shown</td><td rowspan="4">(Each frames are selected from each 10 frames)</td><td colspan="4">Camera: Nikon D5100 Date of Creation: 2/18/2014
Time from: 06.43 AM Video Content: Natural Scene
Dimension: 1920 X 1080 Duration of Video: 30 sec
Frame rate: 10frame/sec Total no of Frames: 300</td></tr>
<tr><td></td><td>10 sec</td><td>15 sec</td><td>30 sec</td></tr>
<tr><td>Fog degraded frames</td><td></td><td></td><td></td></tr>
<tr><td>Enhanced frames using proposed method</td><td></td><td></td><td></td></tr>
</table>

(a) **(a′)**

Fig. 10 **a** Represents real-time dense foggy video. **a′** Represents corresponding enhanced video by using our method

4.1 Qualitative Assessment Evaluation

One of the common, reliable methods to measure the accuracy in the image processing field is the PSNR and RMSE [15]. These methods are commonly used as a measure for quality reconstruction of an image/frame.

Peak Signal To Noise Ratio (PSNR) The most popular distortion measure between the original image and the restored image is the PSNR. The PSNR is used for quality reconstruction of an image/frame. High value of PSNR indicates the high quality of the image/frame. PSNR is used to identify whether a particular algorithm produces better results [15].

PSNR is computed using the following equation:

$$\mathrm{PSNR} = \mathrm{MN}\,\mathrm{max}_{m,n}\, I_{m,n}^{2} / \sum_{m,n} \left(I_{m.n} - \overline{I_{m,n}}\right)^{2} \tag{6}$$

$I_{m,\ n}$ represents a pixel whose coordinates are (m, n) in the original image/frame
$\overline{I_{m,n}}$ represents a pixel whose coordinates are (m, n) in the restored image/frame
MN is the total number of rows and columns, i.e., the total number of pixels in an image/frame.

Here, max is maximum pixel value of image/frame when pixel is represented by using eight bits per sample. This is 255 bar color image with three RGB values per pixel.

Root Mean Square Error (RMSE) The RMSE is used as a measure for quality reconstruction of an image/frame. Low value of RMSE indicates the high quality of the image/frame. RMSE is used to identify whether a particular algorithm produces better results [15].

RMSE is computed using the following equation:

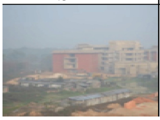
$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{MN}} \sum_{(m.n)} \left(I_{m,n} - \overline{I_{m,n}}\right)^{2}} \tag{7}$$

$I_{\ m,\ n}$ represents a pixel whose coordinates are (m, n) in the original image/frame
$\overline{I_{m,n}}$ represents a pixel whose coordinates are (m, n) in the restored image/frame
MN is the total number of rows and columns, i.e., the total number of pixels in an image/frame

Table 2 describes the qualitative assessment of frames of some videos from SAMEER-TU database in respect of PSNR and RMSE values. In Table 2, PSNR1 and RMSE1 represent PSNR and RMSE values of the image/frame captured in a clear day with the frame captured in the foggy day, while PSNR2 and RMSE2 represent PSNR and RMSE values of the frame captured in a clear day with the enhanced frame using our technique. The higher PSNR value means the frame has a better quality, while low value of RMSE indicates high quality of the frame [16, 17].

Table 2a, b, and c represents images/frames captured in a clear day; a′, b′, and c′ represent corresponding images/frames captured in dense foggy day; a″, b″, and c″ represent restoration of the dense foggy images/frames to its enhanced form using our technique.

Table 2 Qualitative assessment evaluation of some images/frames

Image/Frame captured in a Clear Day	**Image/Frame captured in a Dense Foggy Day**	**Restoration of the Foggy Image/Frame to its clear form using a Technique**	**PSNR1 & RMSE1**	**PSNR2 & RMSE2**
 **a**	 **a'**	 **a'**	PSNR=16.0722 RMSE=40.2376	PSNR=19.2941 RMSE=37.2222
 **b**	 **b'**	 **b'**	PSNR=14.1510 RMSE=50.1982	PSNR=17.4288 RMSE=48.6183
 **c**	 **c'**	 **c''**	PSNR=14.7710 RMSE=46.7403	PSNR=18.1903 RMSE=42.0452

From Table 2, it is observed that PSNR2 value is higher than PSNR1, while the value of RMSE2 is lower than RMSE1 which reflect that the video quality of the enhanced frames using our method is better than the real-time dense foggy frames, i.e., restoration of the real-time dense foggy frames to its clear form is accomplished as far as possible.

5 Conclusion

This paper briefs the creation of SAMEER-TU database of 5,390 natural scene images and 10 videos in outdoor uncontrolled environment in foggy and normal conditions. The paper also describes a technique for enhancing the visibility of visual degraded images or videos in the presence of dense fog. Experimental results reveal that the implemented method performs well for dense fog-degraded visual images or frames, but the limitation of the algorithm is observed when images or frames are captured in a dense fog with very low illumination condition. In the future work, the research team will focus on implementing a fusion method to fuse visual degraded foggy image/frames and its corresponding thermal image/frames to acquire better visibility of the highly dense foggy image/frames in a very low illumination condition.

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