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Defogging of Visual Images using SAMEER-TU Database

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Abstract

Poor visibility in foggy condition is a serious problem for computer vision applications. Most computer vision applications suppose that the input images should have clear visibility but due to foggy conditions, images lose the contrast and color-fidelity, and, therefore, improving visibility is an inevitable task. This paper presents a newly created SAMEER–TU database consisting of 5390 images captured in foggy as-well-as, in clear condition with useful ground truth information. This paper also describes a method towards enhancing the visibility of the foggy images. Finally for verifying robustness of the method, qualitative assessment evaluation is performed as a contributory step.

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*Keywords:*Computer vision; Contrast enhancement; SAMEER-TU database; Single image defogging; Qualitative assessment evaluation.

1. Introduction

Image Processing has been an active research area for the last few decades owing to its wide range of applications in computer vision. Poor visibility in bad weather conditions is the main challenge of computer vision applications. Images in bad weather conditions lose the contrast and color fidelity of the scene, and it reduces the effectiveness of human visual system. Poor visibility in bad weather conditions is mainly caused by atmospheric aerosols, such as fog, haze and rain. Generally, the effect of computer vision applications is limited by heavy fog that degrades the

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contrast information of the scene and significantly reduces the visibility of the image. However, standard filtering does not restore these low contrast images[1,15].

Many research works have been done using contrast enhancement techniques to restore contrast of weather degraded images[1] which do not need any scene depth information and avoid complicated atmospheric scattering model. R. T. Tan[4] presented an algorithm for restoring image contrast from a single input image by maximizing the contrast of the direct transmission while assuming a smooth layer of air light. J. P. Tarel and N. Hautiere[3] 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. P. Zhu. et al.[1] proposed an image clearness technique for fog by using a moving mask-based sub-block overlapped histogram equalization method. K. He. et al.[2] proposed a simple but effective image dark channel prior to remove haze from a single image. Recently, C.O. Ancuti and C. Ancuti[5] 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 SAMEER–TU database in an outdoor environment containing natural scene images captured by both NIKON D5100 Visual Camera and FLIR E60 Thermal Camera. The appearance of an outdoor scene is highly complex and depends on various atmospheric conditions like clear air, mist, fog etc. So, a large set of images is required to study the entire variability of scene appearance. The Society of Applied Microwave Electronics Engineering & Research-Tripura University (SAMEER-TU) Database is being collected for this purpose. The database has also been created to reflect its significance in the field of research for developing efficient algorithms to enhance the visibility of the degraded images for computer vision applications. In this database, total of 5640 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 local meteorological department[12,13]the weather condition is categorized as Foggy, Poor Illumination and Normal conditions. This paper also describes a method for enhancing the visibility of visual degraded images 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 organization of the rest of this paper is as follows. In Section 2, creation of our own developed SAMEER-TU Database is illustrated, in Section 3 a technique for enhancing the fog degraded image is described, and Section 4 deals with Experimental Result and Discussion along with Qualitative assessment of the image. Finally, Section 5 concludes this work.

2. SAMEER-TU Database Creation

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 & Engineering of Tripura University (TU), India. In this database, total 5640 visual images are captured by Visual Camera NIKON D5100. Out of 5640 images, 1020 images are captured in foggy condition, 250 images in poor illumination condition and 4370 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 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 Fig. 1 and Fig. 2 respectively.

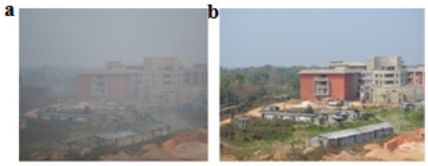

Fig.1.(a) Foggy image; (b) Corresponding clear/normal image.

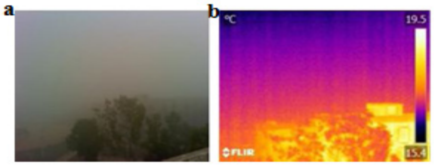

Fig.2. (a) Foggy image; (b) Corresponding thermal image.

This paper mainly focuses on contrast enhancement method for improving the visibility of visual fog-degraded images. 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.

2.2. Designing of SAMEER-TU Database in Foggy Weather Condition

The SAMEER-TU Database consists of 5390 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 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 like fog, haze, rain, etc. 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[11,14]. Clear Condition is generally considered when the visibility remains 3 km[18]. While capturing those images, the temperature normally ranges from 5°c to 20° c, humidity ranges from 95% to 100%, dew point ranges from 5°c to 15° c, wind speed ranges from 1mph (miles per hour) to 3.5 mph (miles per hour) and visibility ranges from 0 km to 3 km[12,13]. Each image is attached with useful ground truth information such as visibility, temperature, humidity, wind speed, dew point temperature and so on.

- **Statistical analysis of Natural scenes in Foggy and Nonfoggy conditions:** Based on visibility parameter obtained per hour from meteorological department[12,13] images have been classified as foggy and non-foggy images. Foggy images are considered when the visibility remains less than 1 km[11,14] while the clear image is normally considered when visibility remains 3 km[18].These foggy and non-foggy images are useful to verify the robustness of the algorithm used in this paper. The distribution of Foggy and Non-Foggy images are shown in Fig. 3.

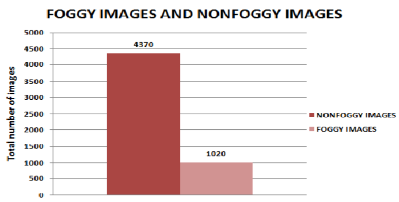

Fig. 3.Distribution of Foggy and Nonfoggy images.

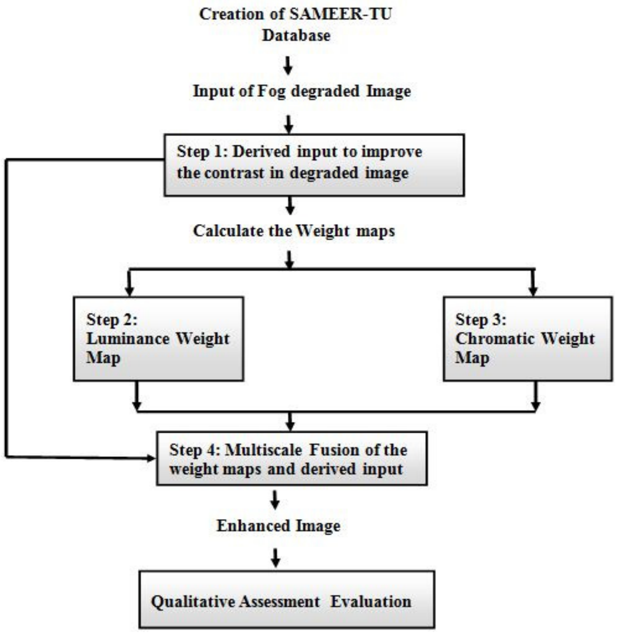

Fig. 4.System flow of the technique.

3. Enhancement of the Fog degraded image in poor visibility conditions

This paper implements a technique for enhancing the fog degraded visual image by using only the single degraded-image information[5] along with qualitative assessment evaluation. Fig. 4 presents the system flow of the technique.

3.1. STEP 1: Derived input to improve the contrast in fog-degraded image

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. The derived input from the foggy image deals with the contrast enhancement that yields a better visibility mainly in the degraded region[5]. The derived input is obtained from the below equation-

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

where $I_2(x)$ is the derived input image.
$I(x)$ is the foggy image.
$\bar{I}$ is the average luminance value of the foggy image 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.
Experiments conducted in each step have been performed in MATLAB using Graphical User Interface (GUI).
Experimental result of STEP 1 is shown in Fig. 5(b).

The contrast enhancement operation mentioned in STEP 1 increases the contrast of the foggy image. But its limitation lies when images contain dense 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 and adds brightness to the image while chromatic weight map measures the saturation gain and adds colorfulness to the image.

3.2. STEP 2: Luminance Weight Map

The luminance weight map measures the luminance gain of the derived input image. This weight is processed based on the RGB color channel information[5]. The Luminance Weight Map is obtained from the below equation-

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

where L represents Luminance computed by averaging the RGB channels and k indexes the derived input.
Experimental result of STEP 2is shown in Fig. 6(a).

3.3. STEP 3: Chromatic Weight Map

The chromatic weight map controls the saturation gain in the derived input image. This weight map is used because in general images characterized by a high level of saturation are preferable[5]. The chromatic weight map is obtained from the below equation-

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

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

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

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. 6(b).

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 $\overline{W}^k$[5]. The multiscale fusion is obtained from the below equation –

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

where I_k symbolizes the input (k is the index of the input) that is weighted by the normalized weight maps $\overline{W}^k$.
Result of STEP 4 is shown in Fig. 7.

Fig.5. (a) Load input dense foggy image and corresponding enhanced image using Graphical User Interface (GUI); (b) Corresponding enhanced image of the real- time dense foggy image by using STEP 1.

Fig. 6. (a) Corresponding Luminance Map of enhanced image by using STEP 2; (b) Corresponding Chromatic Map of enhanced image by using STEP 3.

Fig. 7.Fog-free output image by performing multiscale fusion using STEP 4

4. Results and Discussion

Experiments have been conducted on 180 outdoor real natural scene images taken in dense foggy weather. Due to the scattering of aerosol particles in foggy condition, the scene loses the contrast and color fidelity and thereby reduces the visibility[10]. Therefore, image enhancement algorithm described previously on Section 3 is applied on these dense foggy images 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 increases 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. This technique is implemented on a large number of static dense foggy images from SAMEER-TU Database. Results of experiments are shown in Section 3.

The next phase of the experiment illustrates a qualitative assessment evaluation on the dense foggy images 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).

4.1. PEAK SIGNAL TO NOISE RATIO (PSNR)

The most popular distortion measure between the original image and the restored image is the Peak Signal to Noise Ratio (PSNR).The Peak Signal to Noise Ratio is used for quality reconstruction of an image. High value of PSNR indicates the high quality of the image. PSNR is used to identify whether a particular algorithm produces better results[6]. Peak Signal Noise Ratio (PSNR) is computed using the following equation-

$$PSNR = MN \max_{m,n} I_{m,n}^2 / \sum_{m,n} (I_{m.n} - \overline{I_{m,n}})^2 \quad (6)$$

$I_{m,n}$ represents a pixel whose coordinates are (*m, n*) in the original image.
$\overline{I_{m,n}}$ represents a pixel whose coordinates are (*m, n*) in the restored image.
MN is the total number of rows & columns i.e., the total number of pixels in an image.
Here max is denoted as maximum pixel value of the image when pixel is represented by using eight bits per sample. This is 255 bar color image with three RGB value per pixel.

4.2. ROOT MEAN SQUARE ERROR (RMSE)

The Root Mean Square Error (RMSE) is used as a measure for quality reconstruction of an image. Low value of RMSE indicates the high quality of the image. RMSE is used to identify whether a particular algorithm produces better results[6]. Root Mean Square Error (RMSE) is computed using the following equation-

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

$I_{m,n}$ represents a pixel whose coordinates are (*m, n*) in the original image.
$\overline{I_{m,n}}$ represents a pixel whose coordinates are (*m, n*) in the restored image.
MN is the total number of rows & columns i.e., the total number of pixels in an image.
Table 1describes the qualitative assessment of some images from SAMEER-TU database in respect of PSNR and RMSE value. In Table 1, PSNR1 and RMSE1 represent PSNR and RMSE value of the image captured in a clear day with the image captured in the foggy day while PSNR2 and RMSE2 represent PSNR and RMSE value of the image captured in a clear day with the enhanced image using our technique. The higher PSNR value means the image has a better quality while low value of RMSE indicates high quality of the image[7,8].

Table 1. Qualitative Assessment Evaluation of Some Images

Image Captured in a Clear Day	Image Captured in a Dense Foggy Day	Restoration of Foggy Image to its Clear Form using our 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

PSNR-Peak Signal to Noise Ratio

RMSE-Root Mean Square Error

In Table 1, a, b and c represent images captured in a clear day; a/, b/ and c/ represent corresponding images captured in dense foggy day; a//, b// and c// represent restoration of the dense foggy images to its enhanced form using our technique.

From Table 1, it is observed that PSNR2 value is higher than PSNR1 while the value of RMSE2 is lower than RMSE1 which reflect that the image quality of the enhanced image using our method is better than the real time dense foggy image i.e. restoration of the real-time dense foggy image to its clear form is accomplished as far as possible.

5. Conclusion and Future Work

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

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