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A Novel Method for the Contrast Enhancement of Fog Degraded Video Sequences

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ABSTRACT
Videos taken under fog suffer from degradation such as severe contrast loss. Unfortunately, that effect of fog cannot be overcome by simple image processing techniques. In this paper, a novel method for the contrast enhancement of foggy video sequences is proposed based on the Contrast Limited Adaptive Histogram Equalization (CLAHE), which limits the intensity of each pixel to user determined maximum. Thus, it mitigates the degradation due to fog and improves the visibility of the video signal. Initially, the background and foreground images are extracted from the video sequence. Then, the background and foreground images are separately defogged by applying CLAHE. The defogged background and foreground images are fused into the new frame. Finally, the defogged video sequence is obtained. The experimental results show that the proposed method is more effective than the traditional method. Performance of the proposed method is also analyzed with contrast improvement index (CI) and Tenengrad criterion (TEN).

Keywords
video, fog removal, CLAHE, image enhancement.

1. INTRODUCTION
Video contrast enhancement plays a vital role in video applications such as in outdoor surveillance. Poor video quality reduces the effectiveness of human visual system. This forms the prime cause for accident in air, on sea and on the road. Generally, the effect of outdoor surveillance is limited by heavy fog. Hence, it degrades the contrast information of the scene and significantly reduces the visibility of the video signal. These low contrast videos are not restored by standard filtering. So contrast enhancement based methods are used. There are two types of contrast enhancement methods that deal with fog and they are model based and non model based.

Model based methods are physics based which predict the pattern of image degradation and then restore the image contrast with appropriate compensations. They provide better performance but usually require extra information about the imaging environment or the imaging system [1-3].In paper [4][5] wavelet based methods are used for image restoration. However, these methods are not suitable for general outdoor surveillance videos that present heavy fog and low quality of videos with noise. It is very hard to get a valid imaging model for such conditions. So, these kinds of methods are mainly suitable for still images and not for inter frame processing.
The non-model based methods are histogram equalization and their variation [6-9] and it is the second approach to enhance low contrast image. In paper [10][11], simple local histogram equalization is done by mapping the local histogram of different portions of image to the equalized local histogram. Besides, some papers refer [12-14] on adaptive local histogram equalization. Among this, one of the most classic adaptive local histogram equalization methods is the contrast limited adaptive histogram equalization. Recent works [15-17] address on CLAHE which exploits the local image statistics. This method is also simple and efficient to implement. Therefore, in the proposed method CLAHE is adopted to improve the visibility of fog degraded videos.
The rest of the paper is organized as follows: Section 2 describes the proposed fog removal method. The main content of this section are background extraction, foreground detection, fog removal and image fusion. Section 3 discusses the experimental results and its effectiveness is proved by contrast improvement index and Tenengrad criterion. Section 4 concludes the paper.

2. THE PROPOSED FOG REMOVAL METHOD
Generally, the videos taken under fog suffer from poor visibility. To apply the contrast enhancement process on video sequence, two methods can be adopted. In the first method, each frame is processed separately and the second method processes the background and foreground images separately. In this paper, second method is adopted to improve the visibility of video sequence. The processing flow of the proposed method is given in Figure1.

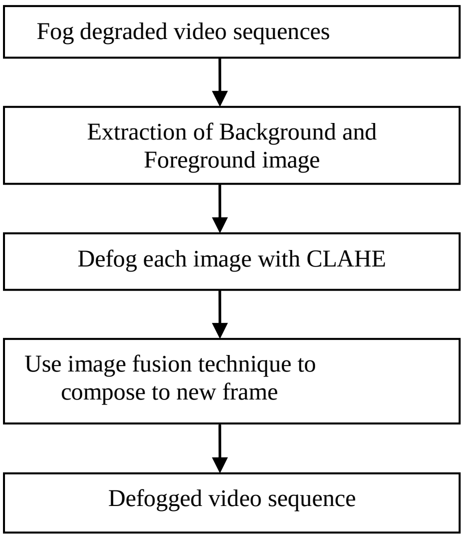

Figure 1: The processing flow of proposed method

Figure 2: Fog degraded video frames: (a) Fog degraded Frame 1, (b) Fog degraded Frame 40, (c) Fog degraded Frame 80,(d) Fog degraded Frame 120

Figure 3: Defogged frames by the proposed method: (a) Defogged result of Frame 1, (b) Defogged result of Frame 40, (c) Defogged result of Frame 80, (d) Defogged result of Frame 120

2.1. Background Extraction

Background extraction is important for moving objects detection. Many existing methods for background extraction like modeling methods or simple averaging mechanisms [18] are available. In Multi-frame averaging method, motion blur and trailing are common flaws. In paper [17] a threshold based algorithm is presented to mitigate these flaws. Although it rectifies the flaws, the problem of the algorithm is that it uses a fixed threshold for all pixels. In this paper, mode algorithm is used for background extraction.

The mode algorithm has some assumption [19][20]. Consider in a very small space of time (e.g.150 frames), the gray level of background will change among a very small range, but the gray level of the foreground will vary with each moving object. Even though in a same foreground object, the gray level will not be the same in different parts. Based on this assumption, it can be concluded that the gray level of the foreground will distribute a certain value and the most frequently occurring pixel value is extracted as the background. Hence, this algorithm gives a good estimate of the background value even in the crowded field.

This algorithm is applied to a sequence of image frames, the color values of a pixel at location (u, v) at time t are I(u, v,t). In RGB color space, I(u, v, t) is a vector with three elements as $I_R(u, v, t)$, $I_G(u, v, t)$, and $I_B(u, v, t)$. The Matrix N (u, v) represents
each given pixel (u, v) with its color values from time t_i to time t_{i-n} as

$$N(u, v) = \{I(u, v, t_i), I(u, v, t_{i-1}), I(u, v, t_{i-2}), ..., I(u, v, t_{i-n})\} \quad (1)$$

The foreground pixel's color values in the periods can be expressed as

$$N_F(u, v) = \{I(u, v, t_{F1}), I(u, v, t_{F2}), I(u, v, t_{F3}), ..., I(u, v, t_{Fj})\} \quad (2)$$

where t_{F1}, t_{F2}, t_{F3}, …, and t_{Fj} are the times when the pixel is occupied by the foreground. The background pixel's color values in the periods can be expressed as:

$$N_B(u, v) = \{I(u, v, t_{B1}), I(u, v, t_{B2}), I(u, v, t_{B3}), ..., I(u, v, t_{Bk})\} \quad (3)$$

where t_{B1}, t_{B2} , t_{B3}, …, and t_{Bk} are the times when the pixel is occupied by the background. $N_F(u, v)$ and $N_B(u,v)$ have the following relationships:

$$N(u,v) = N_F(u, v) \cup N_B(u,v) \text{ and } \varphi = N_F(u, v) \cap N_B(u,v) \quad (4)$$

where φ represents an empty set. Hence, the background is static; the color values of this pixel would approximately be the same during the entire analysis time.

$$I(u,v, t_{B1}) = I(u, v, t_{B2}) = I(u, v, t_{B3}) = ... = I(u, v, t_{Bk}) \quad (5)$$

However, the moving objects may have different colors and shapes at different times for the foreground. The computing formula of background value is

$$I(u,v, t_{Bi}) = Mode(N(u, v)) \quad (6)$$

where t_{Bi} is the time when the pixel is not occupied by the foreground and Mode(N(u, v)) represents the mode of color values in N(u,v).The background color values at location (u, v) can be determined by calculating the mode of N(u, v). After applying the same process to each pixel in the image, a background image will be extracted.

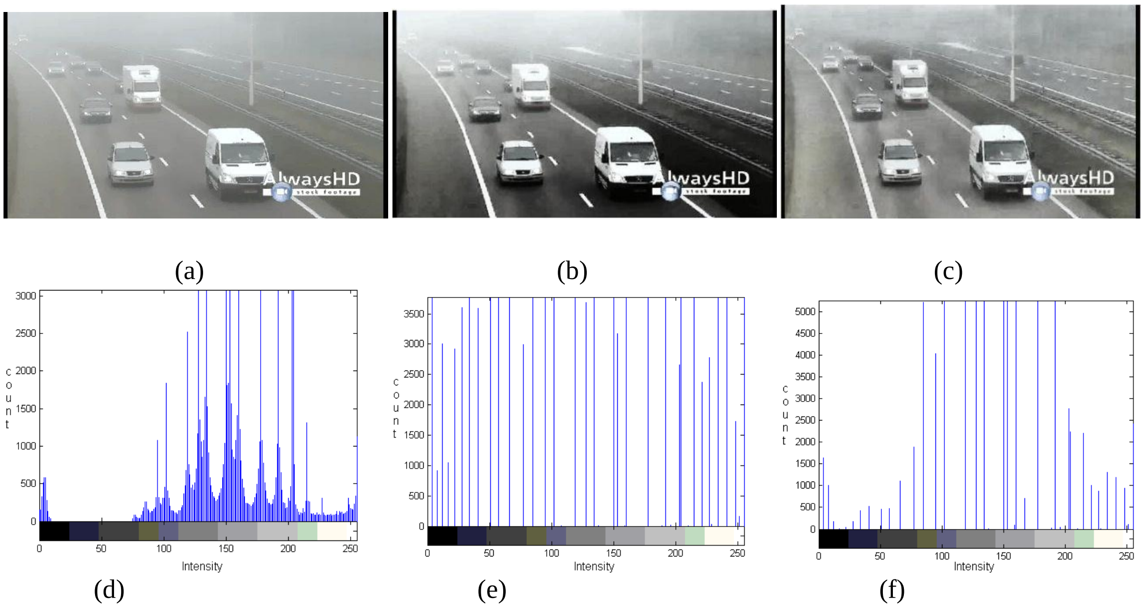

Figure 4: (a) fog degraded frame 1 (b) Defogged result Using HE (c) Defogged result of the proposed method and its corresponding histograms are shown in (d)-(f)

2.2. Foreground Detection

After the background image extraction, each of the frames is analyzed to detect the motion pixels. Here a simple background subtraction method is used for foreground detection.

$$M_i(u,v) = \begin{cases} 1 & \| F_i(u,v) - N_{Bi}(u,v) \| > \alpha \\ 0 & \| F_i(u,v) - N_{Bi}(u,v) \| \le \alpha \end{cases} \tag{7}$$

where

α is the threshold,

$F_i(u,v)$ is the current frame

$N_{Bi}(u,v)$ is the background frame.

For the detected moving pixels, some morphological operations are applied to remove the noise. Then, the motion pixels are bound with boxes and each box region is segmented as foreground image.

2.3. Defogged by CLAHE

After background and foreground image extraction, it is defogged by the intensity modification methods. In the proposed method, CLAHE is used in HSI color space. Because the contrast of the foggy images mainly depends on the intensity values. Thus CLAHE only alters the intensity and it unchanges the hue and saturation components. Usually the video sequences are in RGB color space. So the conversion formulas of color images from RGB to HSI and HSI to RGB are required [21].Finally, at the end of these operations the defogged images are obtained.

The CLAHE method [18] applies histogram equalization to sub-images. Each pixel of original image is in the center of the sub-image. The original histogram of the sub-image is clipped and the clipped pixels are redistributed to each gray level. The new histogram is different from the original histogram because the intensity of each pixel is limited to a user determined maximum. Thus, CLAHE can reduce the enhancement of noise.

The various steps of CLAHE method are divided as follows:

Step 1: The original image should be divided into sub-images which are continuous and non-overlapping. The size of each sub-image is M×N.

Step 2: The histograms of the sub-images are calculated.

Step 3: The histograms of the sub-images are clipped.

The number of pixels in the sub-image is equally distributed to each gray level. Then the average number of pixels in each gray level is given as

$$N_{avg} = \frac{N_{SI-XP} \ X \ N_{SI-YP}}{N_{graylevel}} \tag{8}$$

where

N_{avg} is the average number of pixels,

$N_{graylevel}$ is the number of the gray levels in the sub-image.

N_{SI-XP} is the number of pixels in the x dimension of the sub-image.

N_{SI-YP} is the number of pixels in the y dimension of the sub-image.

Based on the Eq. (8), the actual clip-limit is calculated as

$$N_{C-L} = N_c \ X \ N_{avg} \tag{9}$$

Table 1. CI and TEN values of the Proposed Method and Histogram equalization for different frames.

Input Frame	Histogram Equalization CI	Proposed Method CI	Histogram Equalization TEN	Proposed Method TEN
Frame 5	1.5287	2.0738	16881	23957
Frame 40	1.5375	2.3835	16078	23258

where
N_{C-L} is actual clip-limit.
N_c is the maximum multiple of average pixels in each gray level of the sub-image.

In the original histogram, the pixels will be clipped if the number of pixels is greater than N_c. The number of pixels distributed averagely into each gray level (N_d) is defined by the total number of clipped pixels N_{TC} as

$$N_d = \frac{N_{TC}}{N_{graylevel}} \tag{10}$$

$H_{SI}(i)$ is the number of pixels in each gray level of the sub-image, 'i' is the number of gray level. Using the above equations, the contrast limited histogram of the sub-image can be calculated by the following rules given below:

$$\begin{aligned} &If \quad H_{SI} > N_{C-L}\,,\ H_{NSI}(i) = N_{C-L} \\ &Else\ if \quad H_{SI}(i) + N_d \geq N_{C-L,} \quad H_{NSI}(i) = N_{C-L} \\ &Else \quad H_{NSI}(i) = H_{SI}(i) + N_d \end{aligned} \tag{11}$$

At the end of the above distribution, the remaining number of clipped pixels is expressed as N_{RP}, and then the step of distributed pixels is given by

$$S = \frac{N_{graylevel}}{N_{RP}} \tag{12}$$

This method scans all pixels from the minimum to the maximum of gray level. If the frequency of occurrence of the pixels in the gray level is less than N_{C-L}, the method will distribute one pixel to that gray level. If the search ends before the distribution of all pixels, then it calculates the new step according to Eq. (12) and start new search until the remaining pixels are distributed**.** Thus, a new histogram is obtained.
Step 4: The limited contrast histogram of each sub-image is processed by histogram equalization. Finally, the pixels of the sub images are mapped using linear interpolation.

2.4. Image Fusion

For each frame, its background and foreground images are defogged separately. Then, the defogged background and foreground images are fused to form a new frame. Finally, through the above steps a defogged video sequence is obtained.

3. EXPERIMENTAL RESULTS

The video sequence degraded by fog is used to evaluate the effectiveness of the proposed method. Four frames in a traffic surveillance video sequence captured in a real foggy scene are shown in Figure 2a to 2d.These frames are not continuous frames but uniformly spaced to distinguish the moving objects clearly. These frames have poor contrast and its detail is blurry. The defogged frame by the proposed method is shown in Figure 3a to 3d.The comparison of the defogged frames with the original frames shows better visibility and contrast.

To show the performance of the proposed method, it is compared with the traditional method as shown in Figure 4.The original frame degraded by fog is shown in Figure 4a.The defogged frame by global histogram equalization is shown in Figure 4b.The defogged frame of the proposed method is shown in Figure 4c.Also, its corresponding histogram statistics is shown in Figure 4d to 4f. The histogram of the traditional method shows that the pixels are extended to the whole grayscales uniformly. Thus, the histogram has no peak value. As a result its detail will not be enhanced enough. In the histogram of the proposed method, the pixels are extended to the whole grayscales and the distribution of pixels can enhance the contrast and detail information. Thus, the histogram of the proposed method is close to the histogram of the frame captured in fine weather. The histogram statistics and intuitive visual effects show that the proposed method is more effective than traditional method.

3.1. Performance Analysis

3.1.1 Contrast Improvement Index

The performance of the proposed method is also analyzed objectively by contrast improvement index (CI) [22]. This measure helps to find the efficiency of the proposed method by comparing the original and the restored frame. The contrast improvement index is given by

$$CI = \frac{C_{\Pr ocessed}}{C_{Original}} \tag{13}$$

where C is the average value of the local contrast measured with
a 3X 3 window as follows:

$$C = \frac{\max - \min}{\max + \min} \quad (14)$$

The Comparison of the CI value for the proposed method with the traditional method is shown in Table 1. The higher CI value signifies better contrast improvement in the output image. For frame 40, the CI value of the proposed method is 2.3835 but for histogram equalization it is 1.5375. This clearly shows the effectiveness of the proposed method compared to the traditional method.

3.1.2 Tenengrad Criterion

The Tenengrad criterion (TEN) is based on gradient ∇ I (x, y) at each pixel (x, y), where the partial derivatives are obtained by a high-pass filter with the convolution kernels i_x and i_y. The gradient magnitude is given by

$$S(x, y) = sqrt[(i_x X I(x, y)^\wedge 2 + (i_y X I(x, y))^\wedge 2] \quad (15)$$

And the Tenengrad criteria is formulated as

$$TEN = \sum_x \sum_y S(x, y)^2, \quad for\ S(x, y > T) \quad (16)$$

where T is the threshold. From Table 1 it is clear that the proposed method has higher Tenengrad value which signifies good visibility and sharpness compared to the traditional method.

4. CONCLUSION

This paper addresses the problem of restoring the fog degraded video sequences by CLAHE based method. Although this method enhances the detail information of the image, it can effectively limit the enhancement of the noise. In this approach, the background and the foreground pixels are processed separately. The experimental results show the effectiveness of the proposed method with the traditional method. Besides, the running time of the proposed method can fill the requirement of the real-time processing.

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