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# INTENSITY ENHANCEMENT ON OUTDOOR IMAGES

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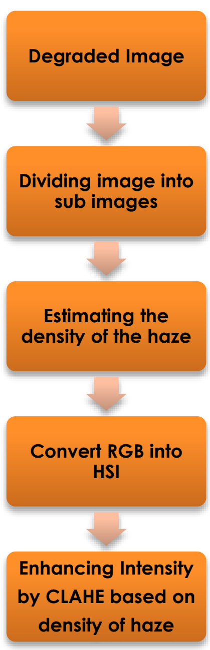
## Graphical abstract




## Abstract

Outdoor images that are captured in bad weather conditions have low contrast and infidelity colours. Under the turbid medium conditions such as haze, mist, fog and drizzle, the light which reaches to the sensor is attenuated by atmospheric particles. These atmospheric phenomena degrade the contrast intensity of outdoor images based on haze density. In this research, we present new method to improve both the intensity and fine details of outdoor scene images. The RGB (Red, Green and Blue) input image is converted to the HSI (Hue Saturation Intensity) colour space and the density of the haze is estimated. Then, we use Contrast Limited Adaptive Histogram Equalization (CLAHE) technique to enhance the degraded intensity based on the estimation of the density of the haze. Our method is effective in a wide range of weather conditions and under different levels of visibility.

*Keywords:* Outdoor images, haze density, CLAHE

## Abstrak

Imej luaran yang di ambil pada cuaca buruk mempunyai kontras yang rendah dan warna yang bercanggahan. Di dalam keadaan yang samar atau keruh seperti jerebu, kabus dan hujan renyai, cahaya yang sampai pada sensor adalah kurang disebabkan oleh pengaruh zarah-zarah atmosfera. Fenomena zarah-zarah atmosfera ini merendahkan keamatan kontras imej luar bangunan yang berasaskan pada kepadatan jerebu. Penyelidikan ini membentangkan satu kaedah baru untuk memperbaiki keamatan dan memperhalusi imej-imej luaran. Input imej RGB (Merah, Hijau dan Biru) ditukar ke ruang warna HSI (Keamatan Warna Tepu) dan kepadatan jerebu dianggarkan. Kemudian, teknik Penyesuaian Histogram Penyamaan Kontras Terhad (CLAHE) digunakan untuk meningkatkan keamatan rendah berasaskan anggaran kepadatan jerebu. Keadah yang dicadangkan adalah sangat berkesan bagi pelbagai jenis cuaca dan pada tahap penglihatan yang berbeza.

*Kata kunci*: Imej-imej luar bangunan, kepadatan jerebu, CLAHE



## 1.0 INTRODUCTION

The enhancement of degraded images is important for different applications of computer vision such as automatic systems for surveillance, intelligent vehicles and outdoor object recognition [1]. Enhancement intensity of hazy image is considered a vital factor in enhancing the images that suffer from degradation and severe contrast loss [2]. Existing enhancement techniques are basically classified into two main categories: spatial domain methods and frequency domain methods [3]. The direct manipulation of pixels in spatial domain increases the popularity of these types of enhancement. In addition, these approaches are straightforward for visualizing the effect. In the last few decades, a bunch of spatial domain methods has been developed for enhancing indoor and outdoor images [4].

In the spatial domain, Histogram Equalization is considered a very popular approach for enhancing the contrast of images [3]. In this technique the intensity of degraded images is redistributed based on the probability distribution of the input image [5]. It generally increases the contrast intensity of the processed image. This approach is useful for images which are bright or dark. To enhance the performance of Histogram Equalization, many methods have been proposed. These methods are generally classified into two categories: global and local Histogram Equalization [6].

Global Histogram Equalization employs the histogram information of the entire input image for its transformation function [7]. This approach is appropriate for general enhancement, but it fails to adapt the local brightness features of the degraded image. It also shifts the mean of image intensity to the middle intensity level regardless of the intensity of the original image [8]. In contrast, Local Histogram Equalization focuses on tackling local brightness problem. However, this approach may amplify noise and produce undesirable output due to over-enhancement. To avoid the excess amplification while maintaining the high dynamic range locally of the degraded image, Contrast Limited Adaptive Histogram Equalization (CLAHE) is proposed by K Zuierveld [9].

Recently, one study [2] used CLAHE in enhancing the intensity of the outdoor hazy images and restored the degraded colour images. The RGB hazy image was converted to HSI colour space. The main reason behind the conversion is that HSI represents the colours as similar as the concept of human visual system [10]. Then, the intensity of the input image is processed by CLAHE without changing the hue and saturation. Finally, the HSI image is converted to the RGB colour space. An underwater study [11] used CLAHE to enhance the intensity of the underwater images that are not visible due to low contrast and scattering of light and the large noise in the environment. Another study for underwater images [12] enhanced the visibility of underwater images by converting the RGB colour space for the degraded underwater image into HSV colour space. Then, CLAHE was applied to saturation (S) and value (V) components. Finally, the processed image is converted to the RGB colour space.

The previous methods that enhanced the intensity and the quality of the degraded images captured in the hazy weather conditions or underwater have their own limitations in enhancing the contrast intensity. The main drawback of these methods is enhancing the intensity of the degraded images without considering the degradation level of visibility. Visibility varies in images captured in hazy weather conditions based on the haze density. The visibility relatively decreases if the haze density increases and vise versa. In underwater images the visibility is related with the depth under the sea level. Hence, enhancing the entire quality of the image or the intensity contrast is inaccurate if the degradation level of the image is not taken into consideration in the enhancement process.

In this research, we proposed a new method to estimate the density of the haze in degraded images. Based on this estimation, we determine the parameters of CLAHE to enhance the intensity of the outdoor hazy images. The suggested method consists of four steps. First is by dividing the input image into two horizontal sub images. Second, for each sub image, the differences between RGB channels are calculated to estimate the density of the haze in the entire input image. Third, RGB colour space of the degraded image is converted to HSI colour space (Hue, Saturation and Intensity). Finally, the intensity component is enhanced by using CLAHE based on the estimation of the density of the haze. Figure 1 shows the steps of the suggested enhancement method.

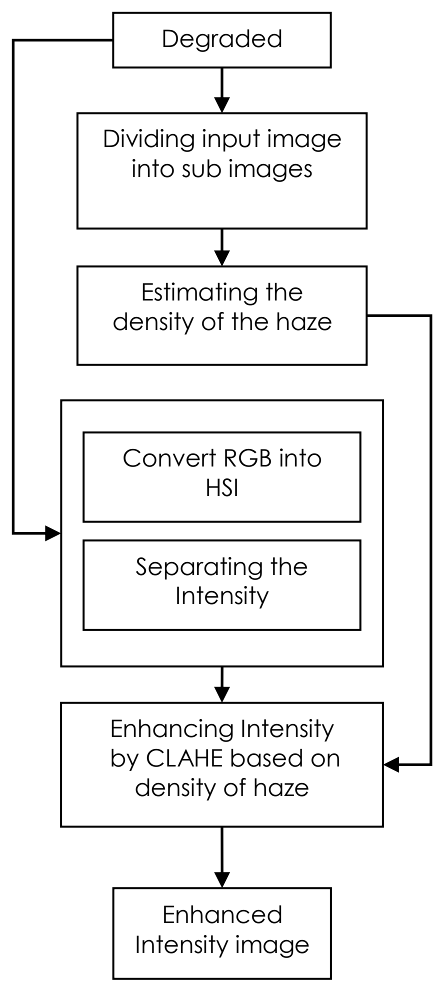
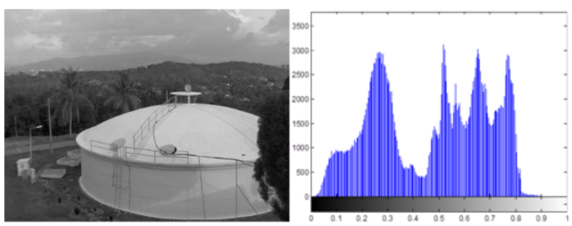


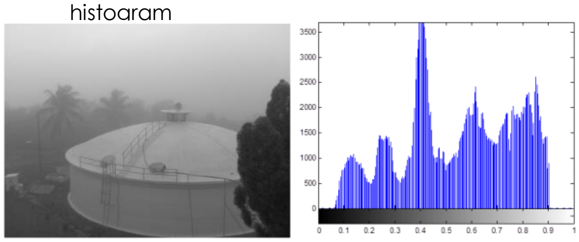

**Figure 1** The steps of the suggested enhancement method

## 2.0 DIVIDING THE INPUT IMAGE

Image histogram is a basic tool that can be used to measure the quality of an image. The histogram of the image intensity can provide us with the essential estimation of the contrast intensity of images. However, comparing intensity of images captured in the hazy weather conditions with images captured in free haze conditions by using histogram may not be able to provide an accurate indication of the presence of the haze and the density of the haze. Figure 2(a) shows the intensity of a clear day image with its histogram and Figure 2(b) shows the intensity and histogram of the same scene but the image captured in hazy weather conditions. The presence of the haze can be seen visually on Figure 2(b). However, the histogram looks quite similar for both images. Hence, we cannot rely on the histogram of an entire image. Instead, we divided the image into sub images based on the nearest objects to observer or camera.



(a) The intensity of clear images and its histogram



(b) The intensity of hazy images and its histogram

**Figure 2** The intensity and histogram of clear and hazy images for the same scene

The atmospheric scattering model is mainly used to describe the hazy scene. It describes the density of the haze in the degraded images based on the distance between the objects and the camera as well as the type of atmospheric particles and airlight. Equation (1) describes the atmospheric scattering model that is used in computer vision and computer graphics [13] [14]:

$$I(x) = t(x) * J(x) + \left(1 - t(x)\right) * A \qquad (1)$$

Where x represents the position of the pixel in the degraded image, I represent the observed image intensity, J indicates to scene albedo (scene radiance), A is the skylight, t indicates the medium transmission that present the light portion that is not scattered and reaches the camera. The medium transmission increases exponentially based on the increasing distance between the camera and the objects. In this model, the attenuation of the scene is essentially based on the distance i.e. the objects that are near to the camera are less affected by the haze, whereas the objects that are far from the camera are highly affected by the haze.

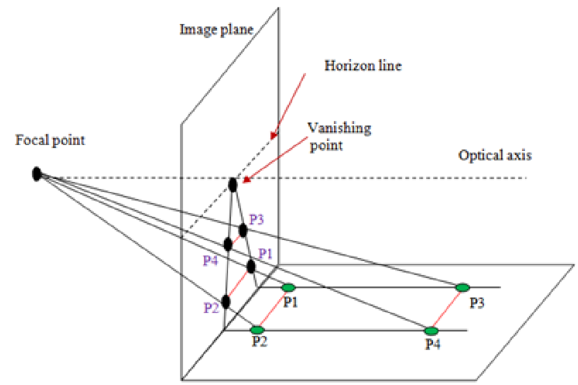



**Figure 3** The geometry of perspective projection of two lines

The images taken with cameras are two dimensional (2D) projections, of the three dimensional (3D) world, and the recovery of 3D information such as depth or area requires a model of the projection transformation. The correct model for human vision and cameras are the central projective model or perspective [15]. Images that are formed under this model disable the calculation of distance measurements because perspective is a non-linear transformation. Light rays passing through one unique point (the focal point) form the projected image [16]. Figure 3 shows the geometry of this perspective projection. The line between the points (p1 and p2) is the nearest to the camera , so it is represented by the lower edge of the image plane, whereas the line between the points (p3 and p4) is located far from the camera and represented in the upper area of the image plane (above of the first line). In other words, the nearest objects projected on the lower part of the image and the distant objects are projected on the upper part of the image. Hence, we divided the image into two horizontal sub images. The lower sub image contains the nearest objects compared with the objects that appear on the upper sub image (especially in the landscape outdoor images). According to atmospheric scattering model, the nearest objects which are located in the lower sub image have less density of the haze (less degradation level), whereas the distant objects which are located in the upper sub image have more density of the haze (more degradation level). Hence, estimating the haze density of sub images provides us with the level of degradation of the entire image.

## 3.0 HAZE DENSITY ESTIMATION

To estimate the density of the haze in degraded images, we analyze the characteristics of RGB channels of each sub image by using the method introduced in [17]. This method measures the relationship between the fog density and the differences between RGB channels. It was found that the differences among the main channels (RGB) becomes high if the density of fog is low and the differences among the channels will be low if the density of the fog is high.

In their work [17] it basically estimates the medium transmission of the hazy image. This method can be exploited to estimates the degradation level of the hazy image. We calculated Euclidean norm to measure the differences among the channels z(x) as follows:

$$\|Z(x)\|_2 = \left(\sum_{i=1}^{3} |z_i(x)|^2\right)^{1/2} \quad (2)$$

Where z(x) is a Euclidean norm for upper and lower images ($Z_{upper}$ and $Z_{lower}$). For each Euclidean norm of sub images we calculate [17]:

$$z_1(x) = R(x) - G(x) \quad (3)$$

$$z_2(x) = G(x) - B(x) \quad (4)$$

$$z_3(x) = B(x) - R(x) \quad (5)$$

Where R, G, B represent the intensity of each channels (RGB) respectively and x represents the spatial location in the image.

## 4.0 CONVERTING RGB TO HSI COLOUR SPACE

The coloured images are generally captured by using RGB colour model. This model is identified by three chromaticities of Red (R), Green (G), and Blue (B) additive primaries. It can produce any chromaticity that is triangle defined by those primary colours. However, RGB colour model is difficult to process [2]. So we converted the degraded images to HSI colour model. The importance of this model relies on two aspects. Firstly, I component (intensity) is separated from other chrominance components (hue H and saturation S). Secondly, these chrominance components are based on how human perceive the colours of the spectrum. In this paper, we enhance the intensity of the haze image. So we converted the RGB input image to HSI colour model. The colour image conversion from RGB to HSI colour model is described as follows [18]:

$$H = \cos^{-1}\left[\frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{\frac{1}{2}}}\right] \quad (6)$$

$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)] \quad (7)$$

$$I = \frac{1}{3}(R+G+B) \quad (8)$$

Where $H = 360^{\circ} - H, \text{if } (B/I) > (G/I)$.

After the conversion, we separated the intensity components for the enhancement process by using the CLAHE based method on the degradation level of the hazy image.

## 5.0 CONTRAST LIMITED ADAPTIVE HISTOGRAM EQUALIZATION (CLAHE)

Contrast Limited Adaptive Histogram Equalization (CLAHE) is exploited to enhance the intensity of the degraded image separated from HSI colour space in the previous step. CLAHE was originally developed to improve the intensity of contrast in the medical images [19]. In this technique, the contrast is limited by clipping the histogram at a user-defined value called clip limit. The clipping limits determine the amount of noise that should be smoothed and hence the amount of the contrast that should be enhanced [12].

The mathematical expression for standard CLAHE technique with uniform distribution can be described as follows [11]:

$$g = [g_{max} - g_{min}] * P(f) + g_{min} \quad (9)$$

Where $g_{max}$ and $g_{min}$ are a maximum and minimum pixel value respectively, g represents the computed pixel value, and P(f) cumulative probability distribution CPD.

For exponential distribution, CLAHE can be described as follows:

$$g = g_{min} - \left(\frac{1}{\alpha}\right) * \ln[1 - P(f)] \quad (10)$$

Where α is the clip parameter. This parameter plays an important role in the enhancement stage. It is generally defined by user without considering the degradation level of the hazy images. In the previous step, we estimated density of the haze by calculating the values of Euclidean norm for the upper and lower sub images ($Z_{upper}$ and $Z_{lower}$). These values can provide us with a clear indication of the density of the haze and can be used to determine clipping parameter as follows:

$$\acute{C} = \left(1 - \frac{Z_{upper}}{Z_{lower}}\right) * C \quad (11)$$

Where the new clipping factor is $\acute{C}$, $Z_{upper}$ and $Z_{lower}$ are the Euclidean norm for the upper and lower parts of the hazy image respectively. C is the default clipping factor (0.01). Unlike the default clipping factor (constant) that is usually used in the CLAHE, the new clipping factor of the suggested method will vary based on the individual presence of the haze in the outdoor scene.

The mechanism of CLAHE is it operates on small regions in the image called tiles and not on the entire image. The contrast of each tile is enhanced, so the histogram of output region approximately matches the histogram that is specified by the distribution parameter.

## 6.0 IMPLEMENTATION

To implement the suggested method and to improve the intensity of the degraded images that are captured in bad weather conditions, we performed the following stages:

### 6.1 Acquisition of Input Images

In this research, we used two image databases for implementing the proposed technique, FRIDA database [20] from French Institute of Science and Technology for Transport (IFSTTAR) and Universiti Sains Islam Malaysia (USIM) database. FRIDA database consists of five categories. First, clear scene images are used as ground truth for evaluation of visibility and contrast enhancement algorithms. Second, images are for scene with heterogeneous fog (HTF). Third, images are for scene with cloudy heterogeneous fog (CHTF). Fourth, images are for scene with homogeneous fog (HOF). Last, images are of scene with cloudy homogeneous fog (CHOF). Universiti Sains Islam Malaysia (USIM) datasets consists of three categories: free haze images, foggy scene images, and rainy scene images.

### 6.2 Dividing Input Image

The input hazy image is divided into two sub images. The lower sub image contains (in the landscape outdoor images) the objects that are relativity closer to the observer than the objects in the upper sub image. According to atmospheric scattering model, the lower division of the image is affected by haze less than the upper division. These differences are exploited in estimating the density of the haze of the input image.

### 6.3 Estimating the Haze Density

The characteristics of two sub images are analyzed to estimate the density of the haze in both images. In the analysis, the differences among RGB channels are calculated by using Euclidean norm. The value of the Euclidean norm indicates the density of the haze in the degraded image. The low value indicates high presence of the haze, whereas the high Euclidean norm value indicates the less presence of the haze.

### 6.4 HSI Conversion

In most of the cases, the image is captured in RGB colour space. To enhance the intensity of the carpeted image, we convert the RGB colour space to the HSI colour space. The latter which has the intensity component is separated from the hue and saturation components. This colour space is similar to the human perceiving the colour and it is useful to separate the degraded intensity to enhance it separately.

### 6.5 Enhancing the Intensity

After separating the intensity of the hazy input image, we use CLAHE to enhance the degraded intensity. The main parameter of CLAHE is clipping limits of histogram that essentially controling the enhancement algorithm. The Euclidean norm that is calculated for the sub images precisely determines the clipping factor of CLAHE based on the level of degradation of the hazy image.

## 7.0 EXPERIMENTAL RESULTS

In this section, we have been evaluated the performance of a suggested algorithm in enhancing the intensity of degraded images. The comparison has been performed on synthesis scenes of FRIDA image database and real scenes of (USIM) image database.

The suggested technique (ICLAHE) has been evaluated and compared with traditional CLAHE and with quality of the free haze scene for the same degraded image. The comparison with free haze scene is to achieve the main aim of this study in enhancing the degraded image to be closer to free haze scene. Quantitative and qualitative tests have been used to evaluate the performance of ICLAHE.

### 7.1 Quantitative Test

To evaluate quantitatively the results of ICLAHE, we use Universal Image Quality Index (UIQI) [21]. This assessment considers three main factors in the assessed image: loss of correlation, luminance distortion, and contrast distortion.

Table 1 shows the average of UIQI test for all scenes (FRIDA and USIM). The range of UIQI is between -1 to 1 where the positive and large value means high quality image. Quality of degrades scenes for FRIDA and USIM databases is calculated. Degraded scenes of FRIDA database consists of different weather conditions: heterogeneous fog, cloudy heterogeneous fog, homogeneous fog, and cloudy homogeneous fog. Degraded scenes of USIM consist of foggy and rainy scenes. The average of quality of clear scene in FRIDA (0.259) and USIM (0.382) is fixed. This table shows that the quality of enhanced image by ICLAHE is mainly closer to the clear scene than the quality of enhanced image by traditional CLAHE.

Figure 4 illustrates the average of UIQI test (in percentage) for all scenes (FRIDA and USIM). In this figure, the average of differences of ICLAHE's results is closer (4%) to the clear scene than traditional CLAHE (25%) under different weather conditions. ICLAHE algorithm varies according to the degradation level of the outdoor scenes; therefore, the efficiency of this method is higher than the efficiency of the traditional CLAHE for images under poor weather conditions.

**Table 1** Average of UIQI test (range -1 to 1) for all scenes (FRIDA and USIM)

| Degraded Scene | | Clear | CLAHE | ICLAHE |
|---|---|---|---|---|
| HTF | 0.230 | 0.259 | 0.386 | 0.322 |
| CHTF | 0.193 | 0.259 | 0.367 | 0.294 |
| HOF | 0.186 | 0.259 | 0.311 | 0.261 |
| CHOF | 0.144 | 0.259 | 0.298 | 0.235 |
| Fog | 0.203 | 0.382 | 0.412 | 0.347 |
| Rain | 0.251 | 0.382 | 0.468 | 0.417 |

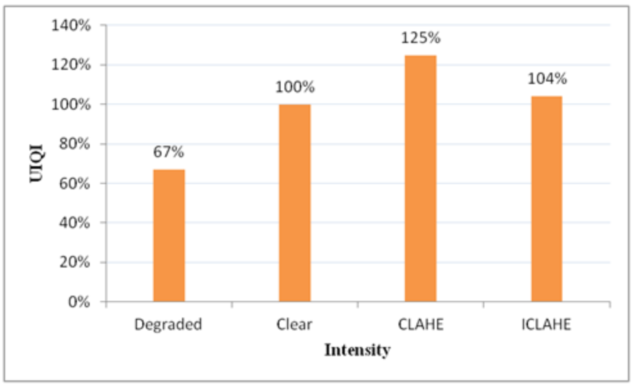



**Figure 4** Average of UIQI test (in percentage) for all scenes (FRIDA and USIM )

## 7.2 Qualitative Test

The results of ICLAHE have been compared visually with the results of traditional CLAHE, clear scenes, and degraded images that are affected by different weather conditions. Figure 5 shows a comparison between enhanced image by CLAHE and ICLAHE with clear scene. In this figure, hazy image is degraded by four types of atmospheric weather conditions (FRIDA). The aim of CLAHE technique is to enhance the quality of the image without taking into consideration of the level of visibility of the degraded image. As a result image is over enhanced and of presence the fog is not evenly distributed (especially with HTF and CHTF in Figure 5), whereas the presence of the fog seems to be natural in ICLAHE. Furthermore, the results of ICLAHE are closer to the intensity of the clear scene. Figure 6 shows a comparison between CLAHE and ICLAHE with clear scene and degraded images (fog and rain - USIM). In this figure, the visual comparison also illustrates that the CLAHE achieves are over enhanced than the ICLAHE. For instance, the contrast of the steel mesh (fog scene) is over than natural contrast in enhanced image by CLAHE, whereas ICLAHE result shows closer to the nature contrast.

Generally, CLAHE technique aims to enhance the image based on the clip limit factor (that is usually fixed); therefore, the results of the technique has higher contrast and brighter than the clear scene. ICLAHE is based on the visibility level of the degraded image in enhancing the outdoor image. Therefore, the results are close to the free haze scene.

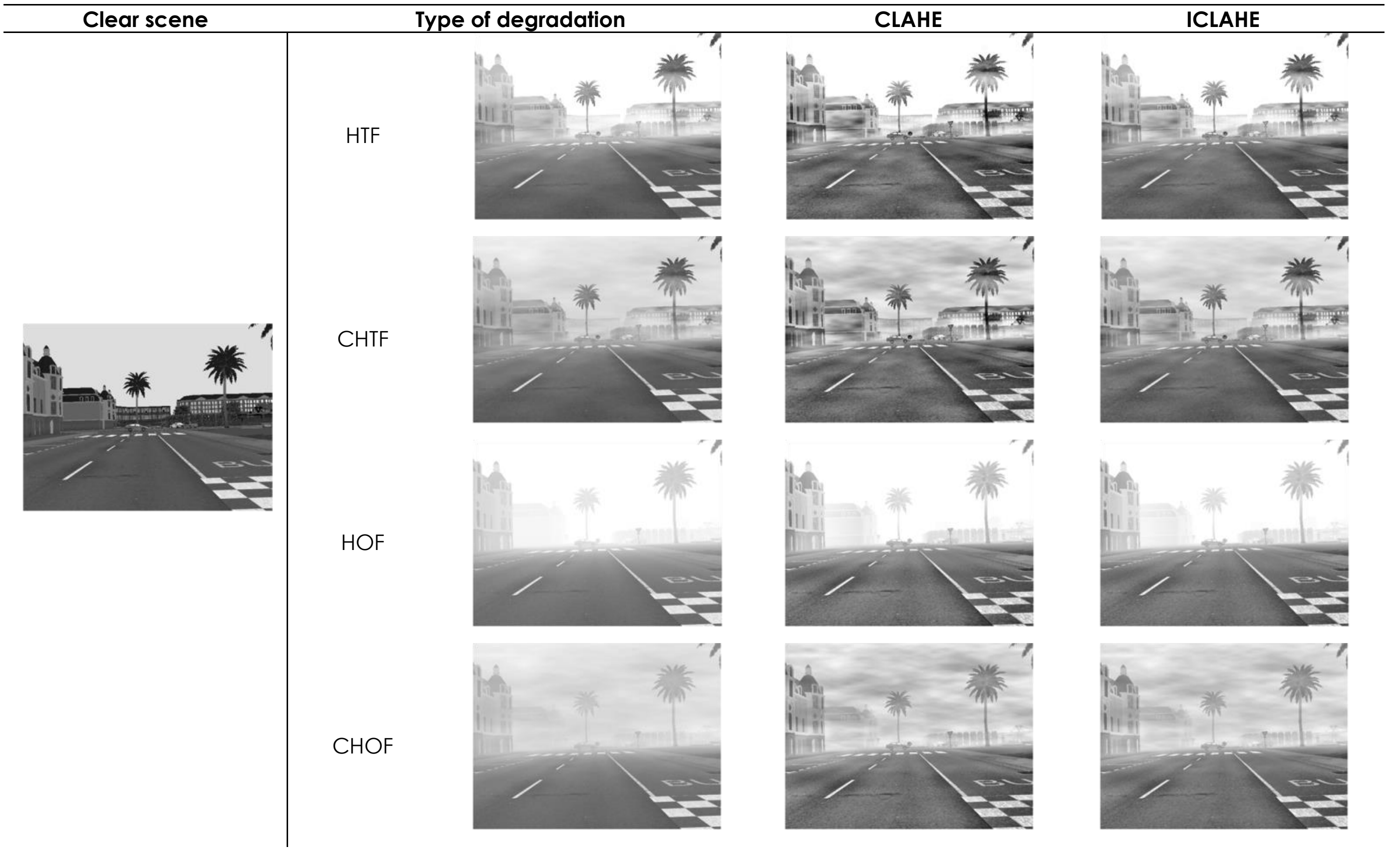



**Figure 5** Comparison with synthesis scenes (FRIDA)

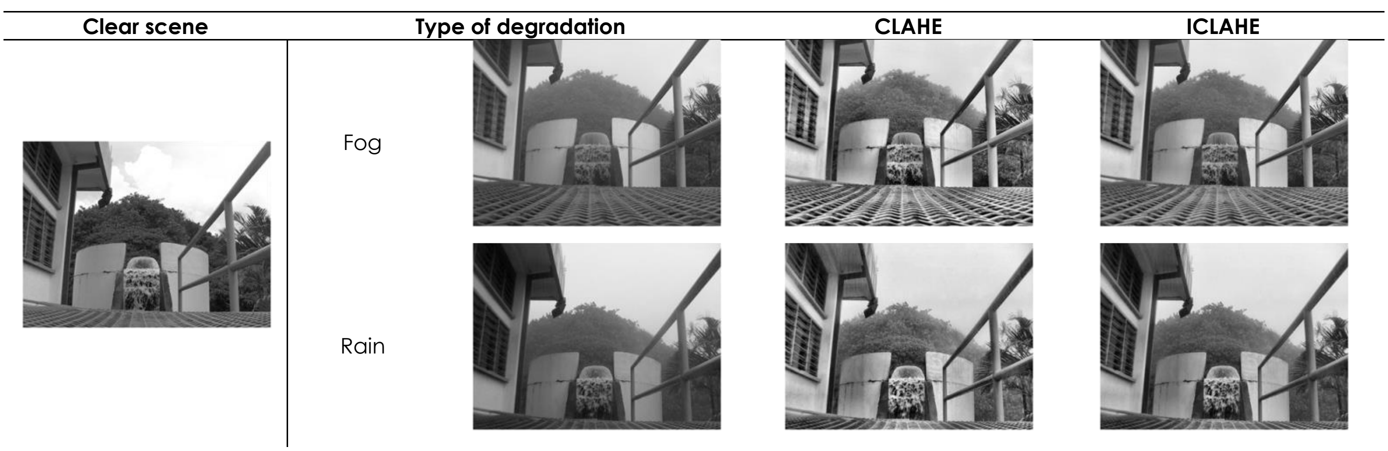



**Figure 6** Comparison with real scenes (USIM)

## 8.0 CONCLUSION

The intensity of outdoor hazy images is degraded by atmospheric weather phenomena such as fog, mist and drizzles. The effects of these phenomena on the image captured in bad weather varies based on the type and size of the suspended particles in the weather and the distance between the camera and objects.

Many techniques are used to enhance the intensity of degraded images. Histogram Equalization and its extended techniques such as Global HE and Local HE are very popular techniques that are used to enhance the image intensity. Recently, CLAHE technique is applied to enhance the degradation of the intensity of the outdoor and under water images. These types of enhancement do not consider the haze density that mainly affects the level of degradation of the captured images.

In this research, we estimated the density of the haze by dividing the degraded image into two horizontal divisions. In each division, we calculated the differences among the RGB channels that reflect haze density which is basically due to the degradation level in outdoor image. The RGB input image is converted to HSI colour space which is similar to human eye. It supports the separation of the intensity component of the input image. Then, we used CLAHE technique to enhance the degraded intensity which based on the level of degradation that we calculated in the previous step.

Our suggested method aims to enhance the quality of degraded intensity to be primarily similar to the intensity of a clear day images. Furthermore, we improved the fine details and increase the contrast of the input images that are affected by the atmospheric weather conditions.

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