International Journal of LNCT, Vol 2(4)
ISSN (Online): 2456-9895

Haze removal foggy images with denoising algorithm

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Abstract

Fog removal is highly desired in both computational photography and computer vision applications. Proposed technique uses a Dark Channel Prior method. Using this method we can directly conclude the thickness of the haze and recover a high quality haze free image, since the foggy images suffer from low contrast and resolution due to scattering of light and poor visibility conditions. Histogram Equalization is applied in the resulted image of dark channel prior method. the noise that affect foggy image can also be reduced by using the Gaussian low pass filter, it is a frequency filtering method compared to other filtering techniques, it corrects variable lighting and removes the high frequency components from image like salt and paper noise etc. By this technique the visual ability and color of the foggy image can be corrected .Experiments are conducted on PSNR and AMBE parameters. Proposed Method has least average AMBE values and Higher PSNR values among other methods.

Keywords

AMBE, Haze removal, Histogram equalization, Gaussian filter.

1.Introduction

Visibility of images often suffers due to fog, mist, and haze present in atmosphere. However, it plays very important role in day to day life such as in video surveillance, navigation control, satellite imaging like environmental studies, weather studies, web mapping and vehicle driving, railway and road traffic analysis. Images which are captured under foggy or hazy weather contains atmospheric degradation particle, as a result light incident on scene get absorbed and scattered. There are many elements which reflect the incident light, bring downs saturation level. This affects low as well high frequency components of the image. Moreover, this degraded image suffers severe contrast loss, bad visibility, very poor performance.

Due to contrast loss image dim especially in distant regions and blurred with surrounding area. In order to get rid of this problem, it is necessary to defog the degraded image [1][2]. Fog formation occurs due to condensation of water vapor into tiny droplets suspended in the air. Water vapor is added to the air in various ways such as wind convergence, water fall, heating of water due to sunlight cause evaporation of water from the surface of oceans, estuary and transpiration from plants and lifting Air Mountain. Produced water vapor begin condensing on dust, ice, salt and other particles which are present in atmosphere, in order to form cloud. Fog forms when a cool, stable air mass is trapped underneath a worm and humid air mass, this process make substantial effect on images and lack visibility and visual vividness in a real time system.

2.Literature review

R.P. Yawale et.al. proposed a method that uses the dark channel prior and histogram stretching methods for removing a fog from the images and obtaining a more clear images. Whereas dark channel prior is used to improve the quality of foggy images by removing a fog and histogram stretching method is used to improve the contrast of the image. The first step is load the image from database. In second step dark channel is estimated. In third step atmospheric light is estimated by using dark channel. In fourth step transmission map is estimated by using above estimated atmospheric light. The fifth step is the scene radiance recovery, with the atmospheric light and transmission map the scene radiance is recovered. In this step fog free image is obtained. In sixth step the fog free image is enhanced by improving contrast of the image using histogram stretching method. Finally enhance image has been obtained. In next step histogram of fog free image is obtained [5].

Negru et al. (2014) proposed an algorithm that was suitable for the image enhancement for the day time fog conditions. The fogginess turns the image processing applications slow and makes them sensitive. This proposed work is based on the mathematical model of the koshmieder's law for computing the atmospheric veil. In this paper, both the quantitative and qualitative evolutions are performed on both the real camera pictures and synthetic images. The main advantage of using this model is the ability to adapt as per fog conditions. This model is also applicable for both the grey scale and colored images. The main application of this algorithm is that it can be ported into mobile phones and provide the driving assistance as a low cost solution [6].

Tarel (2012) used a modification of a common physical model. The issue of depth estimation is not considered in this model which can lead to decreasing the complexity of the proposed algorithm. However, too many parameters should be adjusted which can lead to the limited application of this method. In [2], two versions of the original image were used as the inputs weighted by specific maps. Three weight maps (luminance, chromatic and saliency) were used as weighting components. The basic idea in this fusion-based method was to combine these input images into a single one. The proposed method is very fast and easy to implement. As a consequence, it can be widely used in real-time applications [7].

He et al (2009)used guided image filtering, and proposed simple but effective method for haze removal using dark channel prior method. Most images contain haze free portion which has very low intensity in at least one color. Therefore, thickness of haze may be directly calculated. Output of one filter may be the input for the next guided filter. It can be used for edge preserving and smoothening, and has better results than the popular bilateral filter. It has a significantly faster processing time. A high quality depth map is also created. May not work for images with objects inherently similar to the atmospheric light, transmission then will be underestimated as dark channel has statistical dependence[8].

Y.H.Lia et.al. [9] Advocate the significance of accurate transmission estimation and recast problem as deriving the optimal transmission map directly from the haze model under two scene priors. They introduce theoretic and heuristic bounds of scene transmission to guide the optimum and show that the proposed theoretic bound happens to justify the well-known dark channel prior of haze-free images. With the constraints on the solution space, authors then incorporate two scene priors, including locally consistent scene radiance and context-aware scene transmission, to formulate a constrained minimization problem and solve it by quadratic programming. The global optimality is guaranteed. Simulations on synthetic data set quantitatively verify the accuracy and show that the transmission map successfully captures fine-grained depth boundaries. Experimental results on color/gray-level images demonstrate that their method outperforms most state of the arts in terms of both accurate transmission maps and realistic haze-free images.

3.Proposed algorithm

Dark Channel Prior method is used to estimate the transmission and then we apply dehazing process to enhance foggy image. The foggy image suffers from low contrast and resolution due to poor visual conditions, hence an object recognition become difficult task so the contrast of the resulted image is enhanced by using Histogram Equalization that results a more clear image. The de-noising process is applied by using Gaussian Low Pass Filter. The flow chart of HRFID algorithm is presented below:

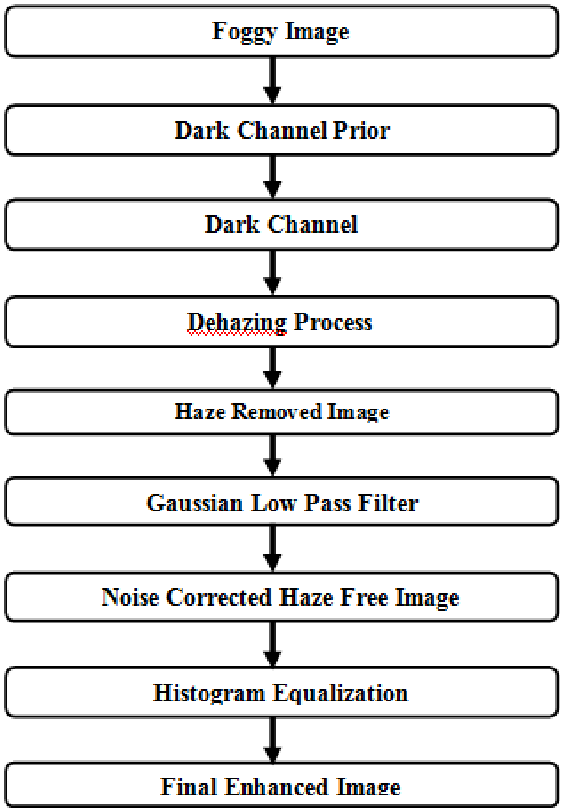


Figure 1 Flow chart of proposed algorithm

Here the algorithm for digital image defogging by using dark channel prior and histogram Equalization method has been design. The atmospheric scattering model describes the formation of haze image by following equation:

$$I(x) = J(x)\,t(x) + A(1-t(x)) \qquad (1)$$

Where I is denotes the haze image, J is the scene radiance, A is the global atmospheric light, and t is the transmission medium. It describes the portion of the light that is not scattered and reaches the camera.

The goal of haze removal is to recover A, t, and J from I.

The above data flow diagram shows the various steps for obtaining defog and enhance image. In this section, the steps of the single image dehazing algorithm are explained in detailed. First we have to start with the dark channel prior.

Dark Channel Prior

The dark channel prior is based on the following observation on haze-free outdoor images. In most of the non-sky patches, at least one color channel has very low intensity at some pixels. In other words, the minimum intensity in such a patch should has a very low value. Formally, for an image I, we define dark channel as:

$$I^{dark}(x) = \min_{c\in[r,g,b]}\left(\min_{y\in\Omega(x)}(I^{c}(y))\right) \qquad (2)$$

Where I^{c} a color channel of I and Ω (x) is is a local patch centered at x. The observation says that except for the sky region, the intensity of I^{dark} is low and tends to be zero, if I is a haze-free outdoor image. Then call I^{dark} as the dark channel of J .
Due to the additive airlight in an atmosphere, the haze image is brighter than haze free image. So the dark channel of the haze image will have a higher intensity in region with denser haze.

Estimation of Background Light

The background light is usually assumed to be the pixel intensity with the highest brightness value in an image. However, this simple assumption often renders erroneous results due to the presence of self-luminous organisms or an extremely smooth surface, e.g., a white fish. In order to increase the detection robustness of background light, a min operation is first performed in every local patch Ω(x) of all pixels x hazy image I .The brightest pixel value among all local minima corresponds to the back ground light A_{λ} as follows-

$$A_{\lambda} = \max_{x\in I}\ \min_{y\in\Omega(\mathrm{x})} I_{\lambda}(y), \lambda\in[r,g,b] \qquad (3)$$

Transmission Estimation

I use dark channel to estimate the transmission .The Haze Imaging Equation is as given below:

$$I_{\lambda}(x) = J_{\lambda}(x)t_{\lambda}(x) + (1-t_{\lambda}(x)).A_{\lambda} \qquad \lambda\in\{red, green, blue\} \qquad (4)$$

I consider the transmission of a local patch Ω(x) as approximately un-variable, and denote this transmission value as $t(x)$.
we can estimate the transmission $t(x)$ simply by

$$t^{*}(x) = 1 - \min_{\lambda}\min_{\lambda}\frac{\min\limits_{y\in\Omega(x)}\ \min\limits_{y\in\Omega(x)} I_{\lambda}(y)}{A_{\lambda}} \qquad (5)$$

In fact, the term

$$\min_{\lambda}\min_{\lambda}\frac{\min\limits_{y\in\Omega(x)}\ \min\limits_{y\in\Omega(x)} I_{\lambda}(y)}{A_{\lambda}}$$

is the dark channel of the normalized hazy image. So equation 4.10 can be expressed in a more concise form:

$$t^{*}(x) = 1 - I^{*dark}(x) \qquad (6)$$

where $I^{*dark}(x)$ represents the normalized hazy image. Equation (6) is the core method of my single image haze removal algorithm. It provides an estimated transmission for each pixel. Its computation is very simple. The transmission maps reasonably describe the thickness of the haze.

Scene Radiance Recovery

With the background light A_{λ} and the transmission t, I can recover the scene radiance J by inverting haze imaging equation:

$$J_{\lambda}(\mathrm{x}) = \frac{I_{\lambda}(x) - A_{\lambda}}{t_{\lambda}(x)} + A_{\lambda} \qquad (7)$$

However, the direct attenuation term $J_{\lambda}(\mathrm{x})\ I_{\lambda}(x)$ in the haze imaging equation is very close to zero when t(x) is very small. The recovered scene radiance from (4.12) is prone to noise. Therefore, I restrict the transmission t(x) by a lower bound t_0 , i.e., I preserve a small amount of haze in very dense haze regions. The final scene radiance $J_{\lambda}(\mathrm{x})$ is recovered by:

$$J_{\lambda}(\mathrm{x}) = \frac{I_{\lambda}(x) - A_{\lambda}}{\max(t_{\lambda}(x), t_0)} + A_{\lambda}\ A_{\lambda} \qquad (8)$$

Gaussian Low Pass Filter

Gaussian filtering is used to blur images and remove noise and detail. two dimension, the Gaussian function is:

$$G(x,y)=\frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}} \qquad (9)$$

A graphical representation of the 2D Gaussian distribution with mean (0,0) and σ = 1 is shown below.

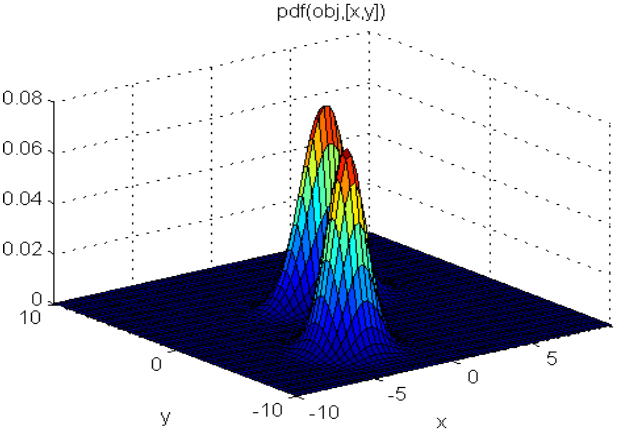


Figure 2 D Gaussian filter

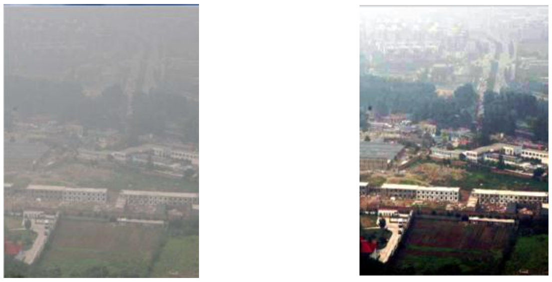
The Gaussian filter works by using the 2D distribution as a point-spread function. This is achieved by convolving the 2D Gaussian distribution function with the image. We need to produce a discrete approximation to the Gaussian function.

Contrast Enhancement by Histogram Equalization

The histogram of an image is the graphical representation of the relative frequencies of the different gray levels in the image. It provides a total description of the appearance of an image. In histogram equalization we consider an image as a 2 dimensional array of gray levels. Suppose input image f(x, y) composed of discrete gray levels in the dynamic range [0, L-1] then the transformation function C(rk) is defined as:

$$C(r_k)=\sum_{i=0}^{k} p(r_i)=\sum_{i=0}^{k}\frac{n_i}{n} \qquad (9)$$

Where $0 \le C(r_k) \le 1$ and k = 0, 1, 2….L-1. In equation (9), ni represents the number of pixels having gray level ri, n is the total number of pixels in the input image, and P(ri) represents as the Probability Density Function (PDF) of the input gray level ri. Based on the PDF, the Cumulative Density Function (CDF) is defined as $C(r_k)$. This mapping in (9) is called Histogram Equalization (HE) or Histogram Linearization. Here $C(r_k)$ can easily be mapped to the dynamic range of [0, L-1] multiplying it by (L-1).



(a) (b)

Figure 3 Original image(a) and its contrast enhanced image(b)

4.Quality parameters

Every above method are compared by statistical point of view by using some standard quality measures.

Peak signal to noise ratio (PSNR)

The PSNR depicts the measure of modification in the original image. This metric is used for discriminating between the original and enhanced image. The easy computation is the advantage of this measure. It is formulated as:

$$PSNR = 10\ \log\ (L-1)^2\ /\ MSE$$

Where MSE is MEAN SQUARE ERROR .The method should not significantly amplify the noise level and thus a high value of PSNR is required A low value of PSNR shows that the constructed image is of poor quality

Absolute Mean Brightness Error (AMBE)

Difference in mean brightness between two images is calculated by Absolute Mean Brightness Error. AMBE is defined as the difference between the input and output mean. Mathematical expression to calculate AMBE between two images is given as:

$$AMBE = |X_m - Y_m|$$

where X_m and Y_m are mean brightness of input and processed image respectively.

Entropy

Discrete entropy E(X) measures the richness of details in an output image after enhancement.

$$E(p) = -\sum_{k=0}^{L-1} p(k)\log_2 p(k)$$

Contrast (C)

The enhanced image must obtain optimum image contrast (C) to distinguish between the object and the background. The contrast for enhanced image ought to be close to the contrast of the original image to attain good image quality. C is calculated using following equation.

$$C = \sqrt{\sum_{m=0}^{L-1} (m - m_{avg})^2 \, p(m)}$$

5.Experimental results

Proposed technique, are implemented on Windows PC having Intel 2.4 GHz processor and 2GB RAM, and run using Matlab 9a.To conduct the experiments on different foggy image by proposed image we have used Waterloo IVC Dehazed Image Database [10]. The dataset consists of 25 hazy images covering diverse outdoor scenes and indoor static objects. We have considered 10 different image from the above dataset. all the images are 24 bit RGB color images. Some of the images are shown in Figure 4.

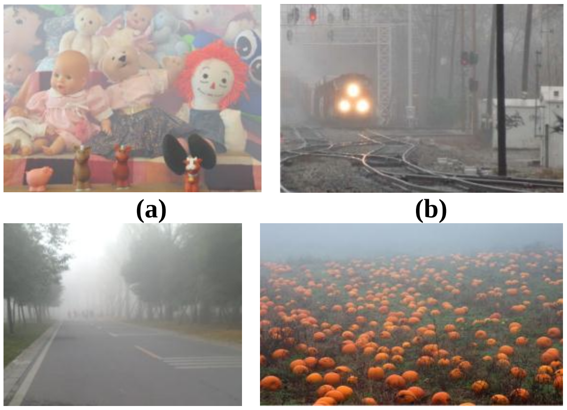

(a) (b)
(c) (d)

Figure 4 Test images

The enhanced images produced by the proposed methods are presented in Figures 5 to 8. The original images have poor brightness in the underexposed regions and brightness is higher in the overexposed regions.

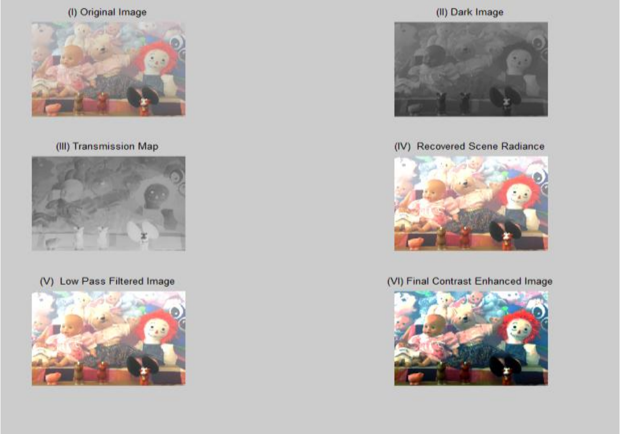


Figure 5 Haze removal Process (I) Input test image 1.(II) dark Channel Image (III) Transmission map (IV) recovered scene radiance by the transmission map (V) Low Pass Filtered Image (VI) Final Enhanced Image

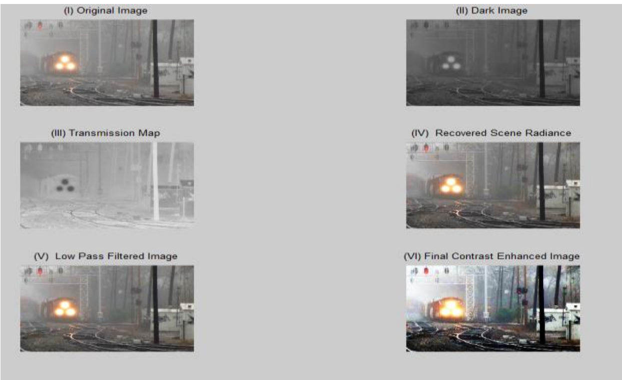


Figure 6 Haze removal Process (I) Input Test image 2.(II) dark Channel Image (III) Transmission map (IV) recovered scene radiance by the transmission map (V) Low Pass Filtered Image (VI) Final Enhanced Image

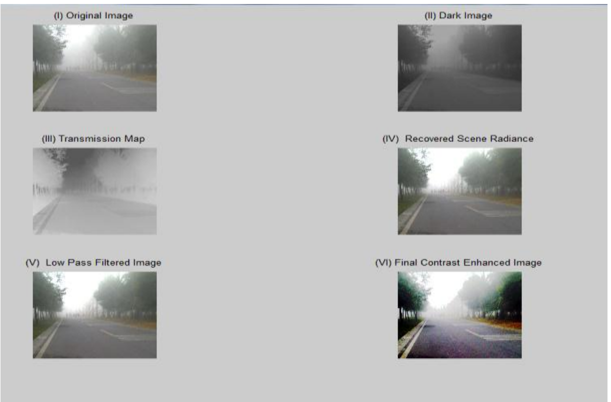


Figure 7 Haze removal Process (I) Input test image 3.(II) dark Channel Image (III) Transmission map (IV) recovered scene radiance by the transmission

map (V) Low Pass Filtered Image (VI) Final Enhanced Image.

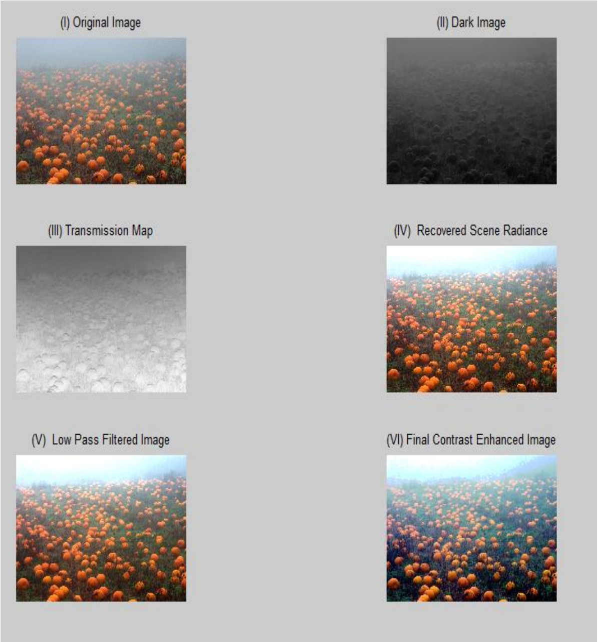


Figure 8 Haze removal Process (I) Input Test image 4.(II) dark Channel Image (III) Transmission map (IV) recovered scene radiance by the transmission map (V) Low Pass Filtered Image (VI) Final Enhanced Image

The qualitative analysis presented in the Figures 5 to 8 and other relative image can be supported by quantitative analysis presented in Table 1.

Table 1 Quantitative analysis on various test image

Image Name	**PSNR**	**AMBE**	**Entropy**	**RMSE**
Test Image 1	29.7867	31.5651	1.6469	0.1317
Test Image 2	31.3938	13.7134	0.8728	0.1106
Test Image 3	32.8256	21.6735	1.6977	0.7195
Test Image 4	32.9808	10.5681	1.9605	0.8567
Test Image 5	32.9351	11.9199	1.5854	0.1201
Test Image 6	31.9205	17.6776	1.2463	0.8716
Test Image 7	31.3423	7.5121	1.3831	0.9685
Test Image 8	33.0241	19.3208	1.5002	0.8213
Test Image 9	30.5073	19.1836	0.3977	0.1185
Test Image 10	31.0532	33.3633	1.3530	0.1309
Average	**31.7837**	**18.6497**	**1.3643**	**0.1035**

Table 2 Shows results of AMBE values on given images by different methods

Methods	**K.He.**	**Tarel**	**Yi-Hsuan Lai**	**Yawale**	**Proposed**
AMBE	0.2524	0.2135	0.1832	0.1727	**0.1035**

The Table 2 shows results of Absolute Mean Brightness Error (AMBE) of proposed method with comparison to other methods. For each analysis, the best results obtained are made bold. Figure 9 represents comparative measurements of AMBE between modified and original image.

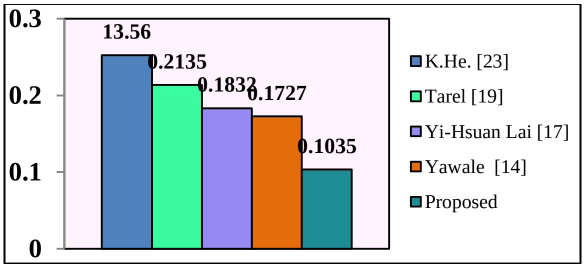


Figure 9 comparative measurements of AMBE between modified and original image.

6.Conclusion

The Haze Removal and Color Compensation with Denoising algorithm proposed in this paper can effectively restore image color balance and remove haze. Dark Channel Prior method is used to estimate the transmission and then we apply dehazing process to enhance foggy image. The foggy image suffers from low contrast and resolution due to poor visual conditions, hence an object recognition become difficult task so the contrast of the resulted image is enhanced by using Histogram Equalization that results a more clear image. The de-noising process is applied by using Gaussian Low Pass Filter.

Proposed technique, are implemented on Windows PC having Intel 2.4 GHz processor and 2GB RAM, and run using Matlab 9a.To conduct the experiments on different foggy image by proposed image we have used Waterloo IVC Dehazed Image Database.

Experiments are conducted on AMBE parameters. Proposed Method has least average AMBE values among other methods. The experimental results demonstrate superior haze removing and color balancing capabilities of the proposed HRFID over traditional dehazing and color correction methods.

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