International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 9, September 2014

A Joint Method for Enhancing a Dehazed Image

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Abstract: ***In this paper, we propose a joint method for enhancing an image from a dehazed image. The joint method includes the fusion strategy, white balancing and contrast enhancement. Haze is an atmospheric phenomenon that degrades the visibility of an image. It scatters the light from an image thus make the image darker. This paper introduces a method to remove the haze from an image and enhance the dehazed image. For this, a fusion strategy is introduced to remove haze. In fusion method, we derive two input images from the original hazy image. The derived inputs are obtained by applying the white balance and contrast enhancement. The weighted maps are measured from the derived inputs. The weighted maps are luminance, chromaticity, and saliency. The derived inputs and normalized weighted maps are fused by using the Laplacian and Guassian pyramid transforms. The output dehazed image is enhanced by using the white balancing and the histogram equalization method. The two properties of histogram transform, gain and non-linearity is computed. The results show that this method is comparative and better than previous methods.***

Keywords: Dehazing, White Balancing, Contrast Enhancement, Histogram Equalization

1. Introduction

With the fast development of technologies and capturing devices millions of images are captured using the capturing devices. The images taken from outdoor scenes can be degraded by the bad atmospheric weather conditions. So the enhancement of an image is a crucial method. The enhancement of an image improves the visibility of such degraded images. In the bad weather conditions, the atmospheric light is scattered and thus tone mapping and contrast enhancement of an image is reduced. The image enhancement algorithms are widely used in many imaging devices in previous. Most of the methods concentrate on tone mapping like gamma correction for making the input raw bit image into a dynamic range. Some tone mapping algorithms are introduced in [1], [2], and [3]. The dehazing techniques are also introduced in many previous papers [4], [5]. In the previous papers the dehazing can be done but there still exist haze particles in the image and the visibility is not clear for that images. In this paper, the dehazed image is enhanced in order to improve the visibility of an image.

The dehazing can be done by using a fusion based strategy. A single hazed image is fused to form a dehazed image. Image fusion is a well-studied process that produces a single output image from a set of input images. The tone mapping algorithms are generally classified into two categories: white balancing and contrast enhancement. The white balancing method maintains the color consistency [6], [7] of the image whereas the contrast enhancement method enhances the luminance of the image. The commonly used technique for contrast enhancement is global histogram equalization. Other techniques are local histogram equalization [8], spatial filtering [9].

From the above literature reviews on image enhancement, some challenging problems of image enhancement are still not solved. 1) How to achieve the contrast enhancement while preserving a good tone. The contrast enhancement and tone mapping have some relation. 2) There are different image enhancement algorithms, how these theoretically relate each other. In the previous methods the fusion strategy for a single image is not introduced. Fusion strategy is used to restore hazy images. This method has some similarity with the recent methods of He et al. [10] and Tarel and Hautiere [11]. In the previous method for image enhancement the white balancing and contrast enhancement can be done separately. This method obviously has some drawbacks. In white balancing the tone can be adjusted and in contrast enhancement it is again biased.

This paper proposes a joint method for dehazing and image enhancement. Dehazing of an image can be done by a fusion method [12]. The input image is a hazed image, from that we derive two inputs. The first input is derived by applying white balance to the image and the second input is derived by applying the contrast enhancement method. The first derived input gives the natural rendition of the image by reducing the chromatic cast whereas the second derived input gives good visibility to the image. We filter some features from the derived inputs. These features are measured by three weight maps: luminance, chromaticity and saliency. These weighted maps are applied to the derived inputs and then apply Laplacian and Gaussian transforms to the derived inputs and the normalized weighted maps. Thus we obtain a dehazed image. The next aim is to enhance the dehazed image. The enhancement can be done by applying the white balance and histogram equalization [13] to the dehazed image.

The rest of paper is structured as follows. In the next section, the methods that deal with haze removal are briefly discussed. In section 3 we discuss about the image enhancement while in Section 4 the experimental results are discussed. In the last section we conclude our proposed model.

2. Image Dehazing Technique

The image dehazing can be done on the basis of a fusion strategy. Fusion is the process of combining several input images into a single output image. In this paper, for fusion

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purpose the inputs are derived from a single image. The inputs are derived by applying some methods and the first derived input depicts the haze-free regions while the second derived input increases visible details of the hazy regions.

The first input I1 is derived by applying the white balancing to the image. The white balancing technique can be proposed in the previous papers. To effectively remove the haze from image we take some concepts from the previous paper shades-of-gray color constancy technique [14]. The white balancing gives the natural rendition of the hazed image. The white balance of the image can be determined by using the concept of Grey-World assumption of Buchsbaum [15], getting the average of R, G, B components from the image. The average color of the whole image is grey. We will find the scale value of the image and then the white balanced image of each component is the product of scale value and R, G, B component of the image. Thus the white balanced image gives good visibility in non-hazy regions.

The second input I2 is derived by applying the contrast enhancement technique to the image, giving enhancement to the regions with low contrast. It can be obtained by subtracting the average luminance value of the entire image I from the original image I. This gives good visibility in the hazed regions. The mathematical expression for calculating the second input is:

$$I2 = \gamma(I - \bar{I}) \quad (1)$$

where γ is a factor that increases linearly the luminance in the recovered hazy regions. The default value for γ is 2.5 and it can be obtained by the expression ($\gamma=2(0.5+\bar{I})$), where $\bar{I}$ is the average luminance value of the entire image. The original hazy image and the derived inputs are shown in Fig. 1.

The next step is to measure the weighted maps from the derived inputs. To make the dehazing better we go for this method. The three weighted maps are: luminance, chromaticity and saliency. It is shown in Fig. 2.

The luminance weight map measures the visibility of image and assigns high value to the region with good visibility and low value to the rest. The weighted map is determined from the RGB color channels. It is measured as for each input I_k where k inputs derived; it is the difference between the average luminance of the image and each RGB values.

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

where L is the average luminance of each RGB component of the image.

The chromatic weight map measures the saturation gain in the image. It gives high saturation to the regions where human eyes feel good visibility. We have to convert the RGB image into high saturated image and select the highest saturated value among them. The chromatic weight map is computed as the distance between the saturation value and max value.

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

where k is the inputs derived, S is the saturation value of the image and S_{max} is a constant that is the maximum value and is taken as 1 and σ is the standard deviation and its default value is 0.3.

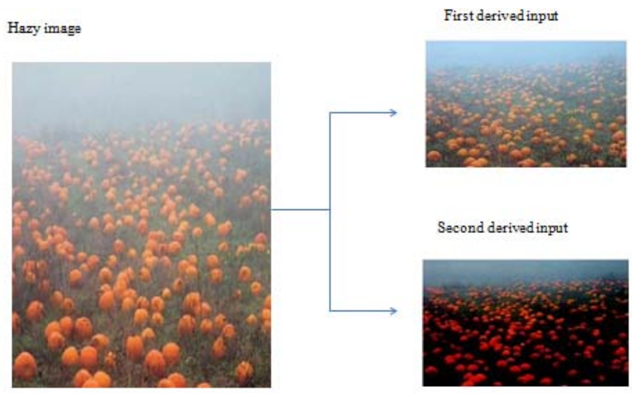

Figure 1: Hazy image and its derived inputs

The saliency weight map measures the degree of conspicuousness with respect to the neighborhood regions. It measures the region that is stands out from the rest of the image. It converts the image to gray if its intensity value is greater than 1. It can be measured as:

$$W_S^k = \left\| I_k^{whc} - \bar{I}_k \right\| \quad (4)$$

where $\bar{I}$ the arithmetic mean value of the image and I^{whc} is the blurred version of the image in order to avoid the unwanted noise from the image. To compute I^{whc} we use a kernel of size (1/16) * [1, 4, 6, 4, 1].

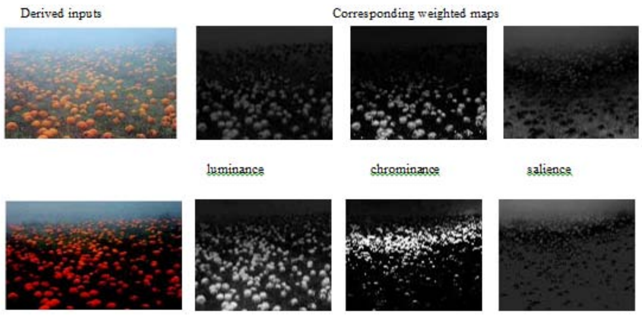

Figure 2: Derived inputs and its weighted maps

The resultant weight map W^k is the product of three weighted maps we computed, $W^k = W^L * W^C * W^S$. To get a consistent result we have to normalize the resultant weighted maps, $\overline{W^k}$. $\overline{W^k} = W^k / \sum_k W^k$.

The final step for the dehazing process is the fusion. The fusion is done with the derived inputs and the normalized weight maps. The fused image F is the sum of the derived inputs and weighted maps.

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

For the fusion process, two transforms are used. The Gaussian transform is applied to the normalized weight map

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ISSN (Online): 2347-3878
Volume 2 Issue 9, September 2014

$\overline{W^k}$ and the Laplacian transform is applied to the derived inputs I^k. The fused image is rewritten as:

$$F = \sum_k G\{\overline{W^k}\}L\{I^k\} \quad (6)$$

3. Image Enhancement

The dehazed image is obtained in the previous section is not enhanced properly. So the enhancement of the image is needed to make good visibility to the image. For this purpose two techniques can be applied to the dehazed image which is white balancing and contrast enhancement. The white balancing can be done on the basis of some assumptions of max-RGB [16] and grey world assumption [14]. The contrast enhancement can be done by the histogram equalization. The enhancement can be done by combining the white balancing and contrast enhancement procedures together to form a good output image. We first of all separate the RGB components from the image and compute the histograms h_c where c is the R, G, B color channels of each component. The next step is to find the intensity difference among the histograms.

$$s_c = h_c - h_{c+1} \quad (7)$$

The probability of the histograms can be calculated which is multiplied with the histogram to obtain the estimated light source of the image which is again multiplied with the constant. The estimated light source of the image is computed as:

$$e_c(\propto) = [(p_c^T \tilde{h}_c^{\propto})^{1/\propto}]/[\sqrt{\sum(p_c^T \tilde{h}_c^{\propto})^{2/\propto}}] \quad (8)$$

where $\propto$ is a parameter which is taken as a constant $\sqrt{3}$. The histogram of white balancing for dehazed image is computed as:

$$\hat{h}_c = \tilde{h}_c/(e_c(\propto) * \sqrt{3}) \quad (9)$$

The histogram based analysis on white balancing is a linear process. The linearity is an important feature of histogram based white balancing.

The next step is to enhance the contrast of an image by using the histogram equalization. It enhances the luminance of the image. The contrast of an image is determined by:

$$C = p_c^T \check{s}_c \quad (10)$$

The contrast enhancement is obtained by maximizing (10) because the maximum value is the luminance value of the image and the minimum value is 0. The equation is rewritten as:

$$\hat{s}_c = \arg max\ p_c^T \check{s}_c \quad (11)$$

The histogram of contrast enhancement for dehazed image is computed as:

$$\hat{h}_c = C \sum_{j=0}^{i} p_{cj} \quad (12)$$

where C is a constant and is taken as the maximum value of (10).

The parameters used to optimize the enhanced image are β and n. the parameter β varies from 0, 0.25, 0.32, 0.5, 1, 2 and the parameter n ranges from 0 to ∞. The equation which uses β and n to compute the enhanced image is:

$$\hat{s}_c = \arg max_{sc} [1/||P_c^{-\beta} s_c||_n] \quad (13)$$

where $P_c = diag(p_{c1}, p_{c2} \dots p_{ck})$.

The two measures were introduced which have a strong relationship among the histogram values we computed. The two measures are the gain of expected context-free contrast G and the nonlinearity of the transform NL from $\check{h}_c$ to $\hat{h}_c$ which is defined as:

$$G = p_c^T \hat{s}_c / p_c^T \check{s}_c\ ,\ NL = ||\nabla(\hat{s}_c - \check{s}_c)||_n \quad (14)$$

If larger the value of N then stronger its non-linearity of transform. The non-linearity of white balancing is close to 0 whereas for contrast enhancement it has stronger value. The parameter β and n controls the contrast gain and the nonlinearity of the model. The value of beta increases the gain increases and nonlinearity decreases. The figure Fig. 3 shows the graph, the relation between β and n for gain and non-linearity.

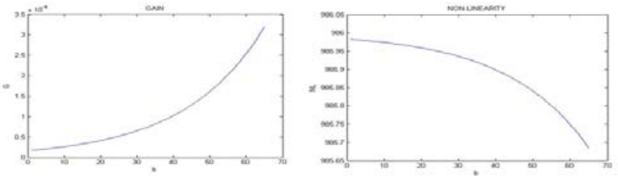

Figure 3: Relation between β and n for gain and non-linearity

4. Experimental Results

Many hazed images were processed using this proposed method. The computation is conducted on platform of MATLAB and Intel Core5 CPU. In the proposed method, we find the luminance, gain and non-linearity of the image. It shows that as the value of β increases the gain increases and nonlinearity decreases. Some results we got from our proposed are shown in Fig.4. As the value of β changes there is some changes can be appeared in the enhanced image. The dehazing and the enhancement method can be done jointly so that the output image gives good visibility. For any hazed image this method removes the haze from the image and enhances the image with good visibility. There are slight differences in the enhancement of image as the value of β varies. This method also shows that the white balancing method is linear whereas contrast enhancement is non-linear.

The proposed method has some advantages. It will overcome the problems of white balancing and contrast enhancement done separately. This method has high efficient than previous method. The time complexity of this method is less. The proposed is very much useful in our real world applications.

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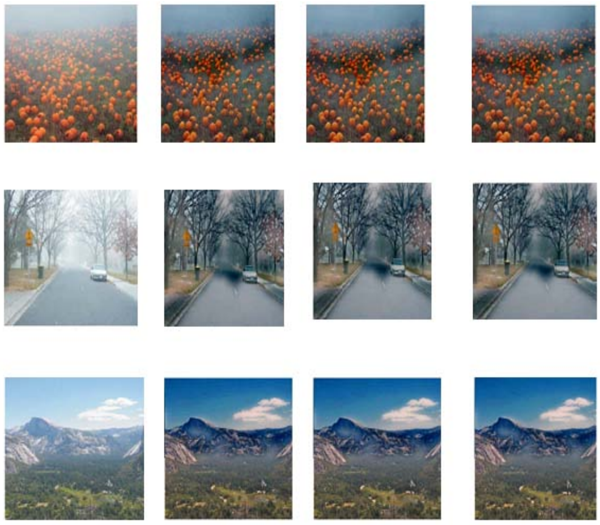

Hazy image β =0 β =0.32 β =2

Figure 4: Hazy image and its enhanced image for different β values

5. Conclusion

A new method for enhancing a dehzed image has been developed. It is a joint method for haze removal and image enhancement. The haze removal uses a fusion strategy to remove the haze from the image and the enhancement uses white balancing and contrast enhancement together. The experimental results shows that the two parameters β and n had a great influence on the enhanced image. When the value of β and n varies the gain and linearity of the enhanced image also varies. The graph is plotted that shows its relationships. This method effectively improves the visibility of an image also overcomes the problem of white balancing and contrast enhancement can be done separately. This method is very efficient. In future this method is also implemented in video.

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