Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 46 (2015) 12 – 19

Procedia Computer Science

International Conference on Information and Communication Technologies (ICICT 2014)

Single Image Haze removal using White Balancing and Saliency Map

Ansia S.[a], Aswathy A. L.[a,*]

[a]*Department of Computer Science, University of Kerala, Kariavattom, Thiruvananthapuram-695581, Kerala, India.*

Abstract

Atmospheric phenomenon such as haze, fog, mist etc is originated by small particles in the air such as dust, smoke or moisture, which reduces the visibility of the outdoor scenes. The background theory behind it is the absorption and scattering of light, that passes through these atmospheric particles. In this paper, we instigate a single image dehazing approach which enhances the visibility of the hazy images. The proposed method focus on contrast based single image dehazing. This approach makes use of white balancing, which eliminates the color cast that is caused by the atmospheric color. In this method, we compute the saliency map of the white balanced image, in order to get the well defined boundaries and uniformly highlighted salient region. Morphological opening is performed on the saliency map, to preserve the size and structure of the objects in the image. At the final step we apply contrast enhancing approach CLAHE, to intensify the local contrast of the images. The performance analysis is done on various natural hazy images. This method has been evaluated with other dehazing algorithms reported in the literature. The experimental results show that the method we developed has the capability to remove the haze efficiently and it can retain the fine details of the regions closer to the horizon.

Peer-review under responsibility of organizing committee of the International Conference on Information and Communication Technologies (ICICT 2014)

Keywords: White balancing; saliency map; morphological opening; clahe ;

1. Introduction

Adverse weather conditions like haze, fog, mist etc diminishes the visibility of the outdoor scenes. The main

* Corresponding author. Tel.: +91 -9847557112.
E-mail address: aswathysat@gmail.com

Peer-review under responsibility of organizing committee of the International Conference on Information and Communication Technologies (ICICT 2014)
doi:10.1016/j.procs.2015.01.042

sources of the haze particles include farming, traffic, industry, volcanic ashes, foliage exudation, combustion products and wildfires. Haze constituted of aerosols that is small particles suspended in gas. Such aerosols commonly arise from natural phenomena, industrial pollution and from complex chemical reactions in which sulphur dioxide vapours are released during ignition and are transformed into small droplets of sulphuric acid. These aerosols are inflated due to the existence of sunlight, excessive moisture, and stagnant air flow. Haze particles are bigger than the air molecules but smaller than the fog droplets. Haze creates problems in the field of terrestrial photography. Due to the effect of light scattering through the haze particles, the distant objects in the scene are less visible. As a result the image appeared as less contrast and the colours are faded.

For the last few years, restoration of the hazy images gains a special attention, because in most image processing applications, we will get the outdoor images and we have to process those images. Restoration of the hazy images plays a vital role in various fields like remote sensing, object recognition, intelligent vehicle and surveillance. Several dehazing techniques have been developed for remote sensing systems. In this, data is recorded in different bands and these recorded bands of reflected light are processed to remove the haze. In the field of Intelligent vehicle system, in most cases, we will get hazy images of the road and we have to dehaze that image, in order to get sign boards, pedestrians, obstacles etc.

There are two types of dehazing, multi-image dehazing and single image dehazing. In multi-image dehazing, several input images are taken in different atmospheric conditions and processed to remove the haze. This type of dehazing[3] produces pleasing results. The main drawback of the multi image dehazing is in its acquisition step. In this step, we have to capture a number of input images for processing, so this type of dehazing needs huge memory, plenty of time and it is very difficult to carry out. Single image dehazing, uses only a single hazy image as input and process this image to generate the dehazed image. Recently, several dehazing methods have been introduced. These methods can be divided into contrast-based and statistical approaches. In contrast based method, we can remove haze by enhancing the contrast. Statistical approach uses depth information of the image for haze removal. Tan's[4], Tarel and Hautiere[5] dehazing method belongs to the first category. Fattal[6], He et al.[7], Kratz and Nishino[8] comes under second category.

Tan's[4] method maximizes the local contrast while constraining the image intensity to be less than the global atmospheric light value. In the dehazing approach of Tarel and Hautiere[5], depth map must be calculated and it should be smooth except along edges with large depth jumps. Fattal[6] employs a graphical model with the supposition that image shading and scene transmission are regionally uncorrelated. He et al.[7] developed their method on the statistical observation of the dark channel, that allows a rough estimation of the transmission map. Kratz and Nishino[8], uses Bayesian probabilistic method for dehazing.

In this paper we suggest an approach for single image dehazing. The proposed method (a) calculates the white balancing of the input image, which discards the color shifting (b) obtain the saliency map of the white balanced image, to find the salient regions (c) perform the morphological opening operation (d) subtracting the average luminance from the input image and apply CLAHE to increase the local contrast of the image.

The rest of the sections are described in the following manner. Section 2 explains the proposed method. Experimental analysis and results are discussed in section 3. Our results are compared with other well known dehazing methods proposed by Tan[4], Fattal[6], Kopf et al.[15], He et al.[7], Tarel and Hautiere[5], Nishino et al.[8], and Ancuti et al.[14] and section 4 concludes the work.

2. Proposed method

The Overview of the proposed method is shown in Fig. 1. The various steps involved in this approach are white balancing, saliency map generation, morphological operation and the contrast enhancement method CLAHE.

2.1. White Balancing

Colour balance is the global adjustment of the intensities of the primary colours (R, G, B). Intensity adjustment is performed to render specific colours, particularly neutral colours and sometimes it is called as gray balance, neutral balance or white balance. In this step, we focus for the natural rendering of images by discarding the chromatic casts that are created by the atmospheric colour. In the past few years, various white balancing algorithms have been proposed. Since we aim for computationally effective dehazing approach, we choose shades of gray colour constancy technique of Finlayson and Trezzi[9]. The main objective of white balancing algorithm is to identify the illuminant colour e(λ).

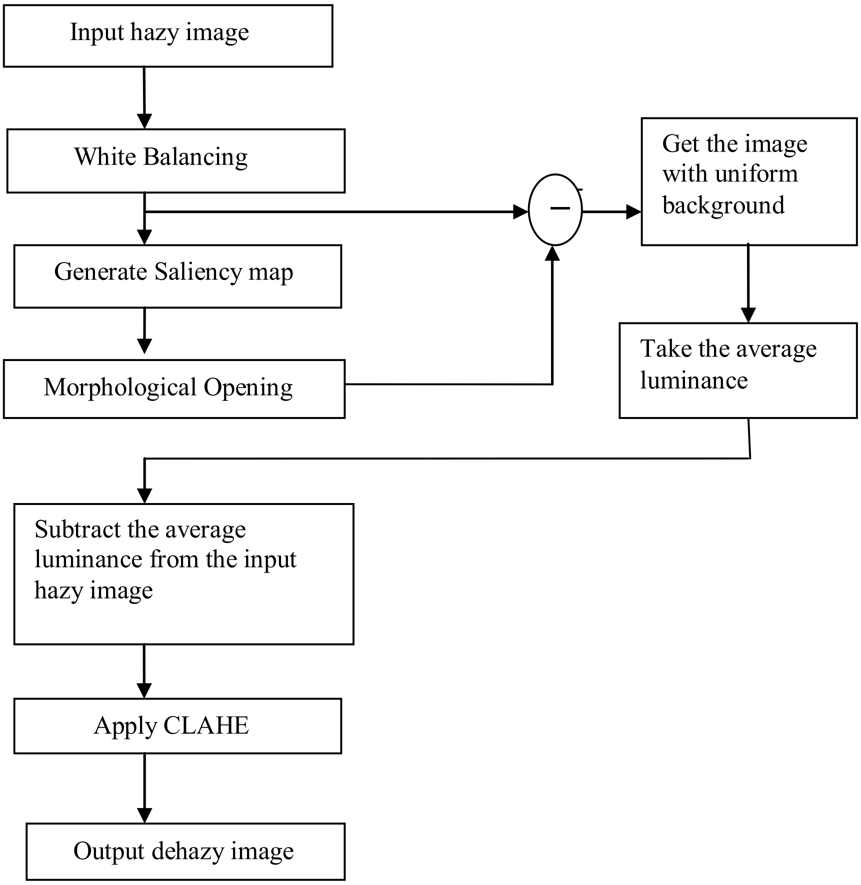

Fig. 1. Overview of the proposed method

In a Lambertian surface, the intensity of an image f can be modelled as :

$$f(x) = \int_w e(\lambda)s(\lambda,x)c(\lambda)d\lambda \qquad (1)$$

Where e(λ) is the radiance given by the light source, λ is the wavelength, s(λ,x) represents the surface reflectance, c(λ) denotes the sensitivity of the sensors and w is the visible spectrum.

The illuminant e, is expressed as

$$e = (R_e, G_e, B_e) = \int_w e(\lambda)c(\lambda)d\lambda \qquad (2)$$

According to Grey-World assumption[10], average reflectance of the scene is gray $\frac{\int s(\lambda,x)dx}{\int dx} = k$ (3)

Assume k is a constant with value 0.5, substitute (3) in equation (1)

$$\frac{\int f(x)dx}{\int dx} = \frac{1}{\int dx}\iint_w e(\lambda)s(\lambda,x)c(\lambda)d\lambda dx \Leftrightarrow$$

$$\frac{\int f(x)dx}{\int dx} = k\int_w e(\lambda)c(\lambda)d\lambda \tag{4}$$

In Shades-of-gray[9] and Grey-edges[11], white balance is defined based on the Minkowiski norm of the images. Grey World[10], calculate the illumination by explaining that the average colour of the entire image raised to a power n is gray.

$$\left[\frac{\int f^n dx}{\int dx}\right]^{\frac{1}{n}} = ke = k\,(R_e, G_e, B_e) \tag{5}$$

In Shades-of-gray[9], n can take any number between 1 and ∞. When n = 1, all the components of the scene contribute uniformly to the average. When the value of n is increased, influence of the components is directly proportional with their intensity. Default value of n = 6. The white balanced result (W) shows good visibility in non-hazy regions and discards the color shifting that is caused by the atmospheric color.

2.2. Saliency map

Saliency map is estimated to determine which regions of the image are the most conspicuous. Saliency of an image can be an item, individual or a pixel. It is the circumstance or quality by which it stands out analogous to its neighbours. Several salient feature detecting methods are there, such as Itti's model[16], Frequency tuned[12], Multi-scale contrast etc. In this method Saliency algorithm of Achanta et al.[12] is used to identify the salient regions. It is according to the notion of centre-surround contrast. The Saliency weight map is defined as:

$$S(x,y) = \left\| \mathrm{I}_{\mathrm{whc}}\,(\mathrm{x,y}) - \mathrm{I}_{\mu}\ (\mathrm{x}\,) \right\| \tag{6}$$

Where I_{whc} represents the Gaussian blurred version of the white balanced image. It is obtained by convolving a small 5*5 (1/16 [1, 4, 6, 4, 1]) separable binomial kernel with the white balanced image. Since the Lab colour space is designed to approximate the human vision, convert this Gaussian blurred version output (I_{whc}) to Lab colour space. Arithmetic mean pixel value (I_{μ}) of L, a and b components are computed and subtracted from the Gaussian blurred version. Saliency is obtained in per pixel fashion by performing the Euclidean distance. We choose the method of Achanta et al.[12], since it is able to produce well distinct boundaries and uniformly accentuated salient regions. The resulted saliency map emphasizes the largest salient regions and it neglect the high frequencies resulting from texture, noise and the blocking artefacts.

2.3. Morphological opening

In this proposed method, morphological opening is used to remove small specularities and texture fluctuations in the image. Morphological opening means erosion succeeded by dilation, by employing the similar structuring element for both operations. Morphological tactics, detect an image with a miniature pattern or arrangement called structuring element. The structuring element is a matrix, that can have any arbitrary shape and size. The structuring element is located at all available regions in the image and it is compared with the similar neighbourhood of pixels. Morphological opening is performed on the saliency map S(x,y), to preserve foreground regions. The objects that are smaller than the structuring element will disappear and larger structures will remain, represented it as O. Subtract the background image O from each channel of the white balanced image W, to create a more uniform background, which represents I1.

2.4. Contrast enhancing by CLAHE

By considering the optical model, the light intensity for each pixel that grasp the observer is depicted by two main factors: direct attenuation (D(x)T(x)) and veiling light, also known as air light (V_∞(1- T(x))). Consider the air light factor from the optical model given below.

$$\mathrm{J(x)} = \mathrm{D(x)T(x)} + \mathrm{V}_\infty(1 - \mathrm{T(x)}) \tag{7}$$

Since the haze is dominant in the hazy images, the hazy regions would have great influence over the average of the image. The air light increases linearly with the distance, so the luminance of these regions is assumed to amplify with the distance. Based on these observations we can subtract the average luminance value of I1 from the input image I, to enhance those regions that have low contrast.

$$L(x,y) = \gamma(I(x,y) - \bar{I}1) \quad (8)$$

The default value of γ is 2.5, gamma is a factor that increases the luminance linearly. The value of gamma gives good results for most of the cases, but there are few exceptions. So we modify the value of gamma, $\gamma = 2(0.5 + \bar{I}1)$, that is correlated with the average luminance of the image. Then apply CLAHE (Contrast Limited Adaptive Histogram Equalization) on L, to maximize the local variation in the image.

CLAHE separates the image into a number of blocks, and then enhance the contrast of each block. The nearby blocks are then joined, by applying bilinear interpolation to ignore fake boundaries. The contrast, exclusively in uniform areas, is restricted by avoiding the amplification of noise that might be present in the image.

We optimize the method by adjusting the number of blocks, count of histogram bins and the clip limit. Contrast limiting is adjusted for all neighbours, from which a transformation function is derived. This is directly proportional to the CDF (Cumulative Distribution Function) of intensity values. CLAHE brim the amplification by clipping the histogram at a pre-ordained value before calculating the CDF. The value at which the histogram is clipped, called clip limit. As the number of blocks increases, we can discriminate small features from the background of the image. The count of histogram bins influence the smoothness of the image. The clipping level trims the distribution at the user defined limit, to modify the contrast.

3. Experimental results

The method we recommended is tested on a large set of different natural hazy and foggy images. Haze includes dirt, gas and other dusty particles that scale down the clarity of natural scenes. Fog is a dense cloud of water droplets.

(a) (b)

Fig. 2. (a) Hazy input (b) Our result

(a) (b)

Fig. 3. (a) Hazy input (b) Our result

(a) (b) (c)

Fig. 4. (a) Foggy image (b) Tan[4] (c) Our result

Fig. 2(b) and 3(b) shows the result of our method, in which we can remove the haze in a better way. Fig. 4(b) and 4(c) shows the comparison between Tan's[4] method and our method. Tan's[4] result shows some oversaturated colours. The proposed method shown in Fig. 4(c) gives good result, in which foreground is more clear, colours are restored and the background details are more clearer than the input hazy image.

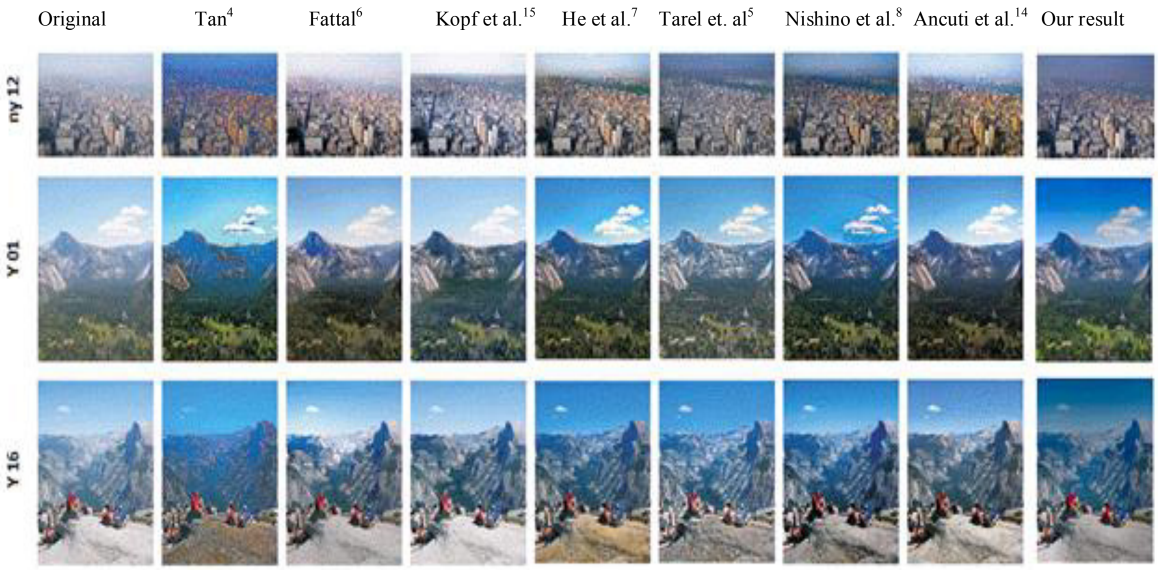

Fig. 5. Comparison of different dehazing techniques-Tan[4], Fattal[6], Kopf [15], He et.al[7], Tarel & Hautiere[5], Nishino[8], Ancuti et al.[14] with our technique.

This method produce better results when compared with other dehazing techniques of Tan[4], Tarel and Hautiere[5], Fattal[6], He et al.[7] and Nishino[8]. Tan[4] method produce results with over saturated colours. The dehazing technique of Nishino[8] introduces some artefacts in regions with infinite depth. Fattal[6] method shows some limitations with dense haze. This is due to the statistical interpretation that requires variance to estimate the depth map.

The Blind measure of Hautiere et al.[13], is used to perform the quantitative evaluation of these results. This is the only existing method for interpreting dehazing operation. In this measure three indicators, e, $\bar{r}$ and Σ are used. e represents edges newly detectable after restoration, $\bar{r}$ represents the mean ratio of the gradients at visible edges and Σ represents the percentage of pixels which become ultimately black or ultimately white after restoration. To compute this indicator we used the parameters which are specified in[5].

Based on the results on Table 1. we can analyse that, Σ indicator produces small values in our technique and other dehazing techniques. In most of the dehazing techniques, indicator e removes most of the edges and yield negative values. The qualitative comparison of the three images shows that Ancuti et al.[14], He et al.[7] and our technique gives positive values for the indicator e. Indicator $\bar{r}$ produces small values for our results, since the proposed method restore the local contrast. If the value of $\bar{r}$ is closer to 1, it produces dehazed images with less spurious edges and artefacts. From the table given below we can analyse that our approach yield minimum value for indicator $\bar{r}$, when compared with the other dehazing techniques.

This method is tested with a huge number of natural hazy images, and observed that, this method produce better results for homogenous hazy images, but it is not working well for the non homogeneous haze. This is one of the limitations of our method. In the case of non homogeneous haze, even though our technique not completely removes the haze, it can remove some haze which is homogeneous in nature and it can restore the colour moderately. This is shown in Fig. 7(b) and some of the farthest portions in the image is also visible to us.

Table 1. Qualitative comparison of the three images (ny17, y01, y17) based on the indicators of Hautiere et al.[13]

Dehazing Methods	Indicators	ny17	Y01	Y16
	e	-0.10	0.04	0.09
Unsharp mask	Σ	1.28	0.27	2.32
	$\bar{r}$	2.29	2.59	1.87
	e	-0.06	0.08	-0.08
Tan [2008]	Σ	0.01	0.01	0.01
	$\bar{r}$	2.22	2.28	2.08
	e	-0.12	0.04	0.03
Fattal [2008]	Σ	0.02	0.02	0.00
	$\bar{r}$	1.56	1.23	1.27
	e	0.01	0.09	-0.01
Kopf [2008]	Σ	0.01	0.00	0.00
	$\bar{r}$	1.62	1.62	1.34
	e	0.01	0.08	0.06
He [2009]	Σ	0.00	0.01	0.00
	$\bar{r}$	1.65	1.33	1.42
	e	-0.01	0.02	-0.01
Tarel [2009]	Σ	0.0	0.0	0.0
	$\bar{r}$	1.87	2.09	2.01
	e	-0.07	0.11	0.01
Nishino[2012]	Σ	0.91	0.71	1.71
	$\bar{r}$	1.79	1.79	1.29
	e	0.12	0.07	0.18
Ancuti [2013]	Σ	0.0	0.01	0.01
	$\bar{r}$	1.54	1.19	1.46
	e	0.14	0.33	0.50
Ours [2014]	Σ	0.00	0.0	0.0
	$\bar{r}$	1.13	1.18	1.02

(a) (b) (c) (d) (e) (f)

Fig. 6. (a) Hazy input (b) White Balancing (c) Saliency map (d) Morphological Opening performed on each channel of the white balanced image (e) Restored output before CLAHE (f) Restored output after CLAHE.

(a) (b)

Fig. 7. (a) Hazy image (b) Non homogeneous haze

4. Conclusion

In this paper, we come up with a unique approach for enhancing the visibility of natural hazy and foggy images. This method make use of white balancing, saliency map of the white balanced image, morphological opening, air light factor in the optical model, and contrast enhancing approach CLAHE in order to remove the haze and enhance the image. The tactics we develop has been tested on a considerable set of legitimate hazy images. The analysis of the result shows that, our method produce better results with less spurious edges and restore the color in a natural way. Since the proposed method does not use any complex calculations such as depth map, it is simple to implement and the time complexity is less.

References

1. P Chavez, An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sens. Environ*.;1998; **24:** 3, p. 459-479.
2. GD. Moro and Halounova, Haze removal and data calibration for high-resolution satellite data.2006; *Int. J.Remote Sens.*, p. 2187-2205,
3. S Narasimhan and S Nayar, Contrast restoration of weather degraded images.Jun 2003; IEEE Trans. Pattern Anal. Mach. Intell.; **25**,:6;p.713-724..
4. RT Tan, Visibility in bad weather from a single image, in Proc. IEEE Conf. Comput. Vis.Pattern Recognit., p. 1-8, Jun. 2008.
5. JP. Tarel and Hautiere, Fast visibility restoration from a single color or gray level image, in Proc. IEEE Int. Conf.Comput.Vis., p. 2201-2208, Sep.-Oct. 2009.
6. R Fattal, Single image dehazing, 2008;ACM Trans. Graph.,SIGGRAPH,. **27**, : 3, p. 72..
7. K. He, J. Sun, and X. Tang, Single image haze removal using dark channel prior, in Proc. IEEE Conf. Comput. Vis. Pattern Recognit., p. 1956-1963, Jun. 2009.
8. L. Kratz and K. Nishino, Factorizing scene albedo and depth from a single foggy image, in Proc. IEEE Int. Conf. Comput. Vis.,p. 1701-1708, Sep.-Oct. 2009.
9. G Finlayson and E Trezzi, Shades of gray and colour constancy, in Proc. 12th Color Imag.Conf.,p. 37-41, 2004.
10. G. Buchsbaum, A spatial processor model for object colour perception.1980; *J. Franklin Inst*.; **310:**1, p. 1-26,.
11. J Van de Weijer, T. Gevers, and A. Gijsenij, Edge-based color constancy, IEEE Trans. Imag Process., vol. 16,no. 9, p. 2207-2214, Sep. 2007.
12. R Achanta, S Hemami, F. Estrada, and S. Susstrunk, Frequency-tuned salient region detection, in Proc. IEEE Conf. Comput. Vis. Pattern Recognit., p. 1597-1604, Jun. 2009.
13. N. Hautiere, J. –P. Tarel, D. Aubert, and E. Dumont, Blind contrast enhancement assessment by gradient rationing at visible edges. *J. Image Anal. Stereol.2008;* **27**:2,pp. 87-95.
14. Codruta Oriana Ancuti and Cosmin Ancuti, Single Image Dehazing by Multi-Scale Fusion, IEEE Transactions on Image Processing, vol. 22, no.8, pp. 3271-3282, August. 2013.
15. J. Kopf, B. Neubert, B. Chen, M. Cohen, D. Cohen-Or,O.Deussen, M. Uyttendaele, and D. Lischinski, Deep photo: Model-based photograph enhancement and viewing, ACM Trans. Graph., vol. 27, no. 5, p. 116, 2008.
16. L. Itti, C. Koch, and E. Niebur, A model of saliency-based visual attention for rapid scene analysis, IEEE Trans. Pattern Anal. Mach. Intell., vol. 20, no. 11, p. 1254-1259, Nov. 1998.