Single Image Dehazing Using Improved Dark Channel Prior

Conference Paper · February 2015

DOI: 10.1109/SPIN.2015.7095426

5 authors, including:

Gupta Ashutosh
Amity University

Bhavin V Kakani
Nirma University

Single Image Dehazing Using Improved Dark Channel Prior

Yogesh Kumar, Jimmy Gautam, Ashutosh Gupta
Department of Electronics and Communication
Amity University
Noida, India
Ykumar2@amity.edu, jgautam@amity.edu

Bhavin V. Kakani, Himansu Chaudhary
Electronics and Communication Engineering
Institute of Technology, Nirma University
Ahmedabad, India
Bhavin.kakani@nirmauni.ac.in

***Abstract*—Huge quantities of suspended particles in our atmosphere, cause scenes to appear hazy or foggy, this reduces visibility of objects and their contrast, and makes detection of objects within the scene more difficult. Most existing algorithms are based on a strong, statistically based prior, the dark channel prior. We introduce an improved Dark Channel Prior method for dehazing image. The transmission map is refined by opening (eroding and dilating) it, thus reducing the halo and block effect.Our method recovers the true radiance of distant objects and the problem of bluishness is reduced.On the basis of color information ω has been made adaptive.The results show that our method is effective in comparison with other methods.**

***IndexTerms*—Dehazing, Dark Channel prior, Erosion, Dilation.**

INTRODUCTION

Image dehazing is a highly challenging task, involving meteorology, physical optics and also computer vision and computer graphics. Haze along with fog and clouds are limiting factors for optical range in the atmosphere and heavily reduce dividing line i.e. contrast in visual scenes.

Haze-free images are more visually pleasing. Second, most image processing algorithms, from lower to high-level object recognition, usually assume that the input image as the scene radiance. The operation of computer vision algorithms (*e.g.*, feature sensing, filtering, and analysis) will necessarily undergo from the biased, low-contrast scene radiance.

Today need for image dehazing has grown as we deal with the digital images mostly taken in bad conditions.Image-dehazing is a very challenging problem as it depends on unknown depth information and the input isonly a single image, the problem is under-constrained.

Theatmospheric scattering mode1[l]-[7] provides the main base and this equation had been widely used in image dehazing. The formation ofa hazy image is described as follows:

$$\boldsymbol{I}(x) = t(x)\boldsymbol{J}(x) + \big(1 - t(x)\big)\boldsymbol{A} \qquad (1)$$

Where $\boldsymbol{I}$ is the noticed hazy image, $\boldsymbol{J}$ is the scenery radiance, $\boldsymbol{A}$ is the global atmospheric light, and t is the medium transmission. It describes the portion of the light that is not scattered and reaches the camera. The task is to recover $\boldsymbol{J}$, $\boldsymbol{A}$, and t from $\boldsymbol{I}$ for haze removal.

The first term $\boldsymbol{J}(x^*)t(x)$ called direct fading [1, 2, 4], and the second term $\boldsymbol{A}(1 - t(x))$ is called atmospheric light[1, 2, 4]. Direct fading describes the scene radiance and its disintegration in the medium, while atmospheric light results from previously spread light and leads to the budging of the scene color. When the atmosphere is uniform, the transmission (t) can be stated as:

$$t(x) = e^{-\beta d(x)} \qquad (2)$$

where βsignifies the quenching coefficient of theatmosphere. It indicates that the scene radiance is weakened exponentially with the scene deepness d.

He et al. [1] proposed a novel single image haze removal method using dark channel priorand refined the transmission map using soft matting algorithm. Using this method, direct estimation of the transmission map of the haze is possible and can be used to recover a high quality haze-free image. However, this method suffers from high computing cost.

Chengming Zou and Jinrui Chen [8] proposed a method to refine the dehazed image by dilating and eroding it, thus refining block effect and halo effect. However this method leads to blurring of images and details are reduced.

In this paper, we introduced an improved single image dehazing method, in which we refine the transmission map by eroding and dilating it, we use this refined transmission map for generating the dehazed image thus reducing block and halo artifacts, while preserving the details. Compared to [8] this method can obtain better results.

IMPROVED DEHAZING ALGORITHM

For clarity of exposition we begin by introducing the dark channel prior first. Later in this section, the details regarding our approach and steps are provided. As mentioned earlier that a single image is under constraint, therefore a correct assumption has to be made for efficient dehazing.

A. Dark Channel Prior

The concept of dark channel prior is based on our observation of outdoor haze-free images. As per the prior, in most of the local regions in haze- free images that aren't sky, very often some pixels in at least one of its colour channels(RGB) have very low intensity or close to zero. The dark channel$J^{dark}$of

$\boldsymbol{J}$(the haze-free image) is defined as (Fig. 1)

Fig. 1 Haze-free images (top)[12]-[14] and their corresponding dark channel (below)

$$J^{dark}(x) = \min_{c\epsilon\{r,g,b\}}\left(\min_{y\epsilon\Omega(x)}\big(J(y)\big)\right) \qquad (3)$$

where $J^c$is a colour channel of J and $\Omega(x)$ is a local patch centered at x. This statistical observation is called the *dark channel prior*

$$J^{dark}(x) \to 0 \qquad (4)$$

Three factors play important role in the low intensity of dark channel prior: a) colored objects having low reflectivity; b) shadows of stationary or moving objects; c) dark physical articles or objects, e.g., stones and dark tree trunks. In outdoor environment these objects forms shadows which provides really dark channels.

B. Estimation of Atmospheric Light

In the following section, a method to estimate atmospheric light ***A*** has been proposed [1]. In many of the previously published work, the color of the most haze-opaque region is used as atmospheric light ***A*** [4] or as ***A***'s initial guess [9]. However, slight care has been paid to the sensing of the "most haze-opaque" region.

Tan[4] has assumed that the atmospheric light (***A***) is globally constant.

Therefore we use it to reflexively estimate the atmospheric lights in all images shown.

C. Estimating the Transmission

In this, we can use the atmospheric light ***A***from section B. Here it is assumed that the transmission in the local patch*Ω(x)* is constant. The dark channel $J^{dark}$of J(the haze-free image) is defined by the equation (3),and since J^{dark}tends to be zero and as A^c, the corresponding channel of the atmospheric light is always positive, it may be written:

$$J^{dark}(x) = \min_{c\epsilon\{r,g,b\}}\left(\min_{y\epsilon\Omega(x)}\left(\frac{J^c(y)}{A^c}\right)\right) = 0 \qquad (5)$$

This can be used to estimate the transmission for that patch *Ω(x)* by using equation (5) into the image formation model equation (1), however now in combination with the min operator:

$$\min_{c}\left(\min_{y\epsilon\Omega(x)} I^c(y)\right) = t(x)\min_{c\epsilon\{r,g,b\}}\left(\min_{y\epsilon\Omega(x)}\big(J(y)\big)\right) + \big(1 - t(x)\big) \qquad (6)$$

with $t(x)$(x)denoting the transmission in a local patch, and as $J^{dark}(x) \to 0$, equation (6) leads to

$$t(x) = 1 - \min_{c\epsilon\{r,g,b\}}\left(\min_{y\epsilon\Omega(x)}\left(\frac{I^c(y)}{A^c}\right)\right) \qquad (7)$$

which is a direct estimation of the transmission for each local patch. So, for the sky region, we have

$$\min_{c\epsilon\{r,g,b\}}\left(\min_{y\epsilon\Omega(x)}\left(\frac{I^c(y)}{A^c}\right)\right) = 1 \; and \; thus \; t(x) \to 0 \qquad (8)$$

Since the sky is at infinite and tends to have zero transmission, the Equation (7) gracefully handles both sky regions and non-sky regions.As we know that even on clear days the there are particles in the air. There always exist some hazes when we look at distant objects. For this reason, we can optionally keep a slight amount of haze for the distant objects so that image seems natural, by introducing a constant parameter ω ($0<\omega\leq 1$) into equation (7):

$$t(x) = 1 - \omega \min_{c\epsilon\{r,g,b\}}\left(\min_{y\epsilon\Omega(x)}\left(\frac{I^c(y)}{A^c}\right)\right) \qquad (9)$$

Therefore we adaptively keep more haze for the distant objects. The value of *ω* is application based. As we know that the recovered scene radiance is over concentrated for a small patch size, thus as we decrease the patch size we can use slight lower value for *ω* (≈0.8) and for large patch size we can increase the *ω* value. We try to fix it to 0.95 for all practical results presented in this paper.

D. Opening the Transmission map

We refine the transmission map by opening it. Eroding and Dilating are the fundamental operations of morphology, widely used in the image processing. Eroding of **A** by **B** is defined as

$$\boldsymbol{A} \ominus \boldsymbol{B} = \{z|\ (\boldsymbol{B})_z \cap A^C \neq \phi\} \qquad (10)$$

where **B** is the structure element. Eroding is to shrink the image in one manner and to some degree controlling by a structure. That **A** is dilated by **B**meansthat all the original points of **B** construct a new set. Aftermapped and moved, **B** and part of **B** overlapped. Dilation is defines as

$$\boldsymbol{A} \oplus \boldsymbol{B} = \{z|\ \boldsymbol{B}_z \cap \boldsymbol{A}^C \neq \phi\} \qquad (11)$$

Opening generally smoothes the contours of the objects in the image, breaks narrow isthmuses, and eliminates thin protrusions. The opening of set **A** by structuring element **B** is defined as

$$\boldsymbol{A}^{\circ}\ \boldsymbol{B} = (\boldsymbol{A} \ominus \boldsymbol{B}) \oplus \boldsymbol{B} \qquad (12)$$

Thus opening **A** by **B** is the erosion of **A** by **B**, followed by dilation of the result by **B**. We apply opening by eroding and dilating the transmission map and the structure elements are line and disk respectively.

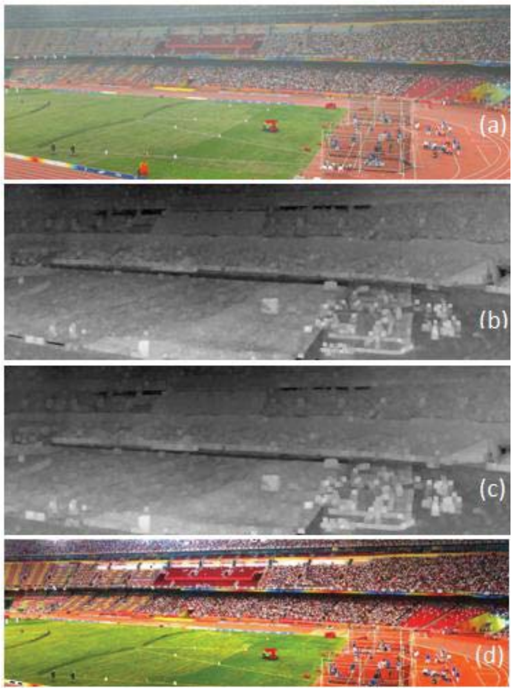


Fig. 2 (a) Input image[10], (b) Transmission map, (c) Opening the Transmission map, (d) Our results.

Rediscovering the Scene Radiance

Having the transmission map, the scene radiance according to equation (1) can be recovered. However, since the direct attenuation term $J(x)t(x)$ can be very close to zero, the transmission is restricted to a lower bound t_0 for example t_0 = 0.1, since the scene radiance is typically not as bright as the atmospheric light A. The final scene radiance $J(x)$ may then be recovered by:

$$J(x) = \frac{I(x) - A}{max(t(x), t_0)} + A \qquad (13)$$

A typical value of t_0 is 0.1 [1]. Since the scene radiance is usually not as bright as the atmospheric light, the image after haze removal looks dim. So we increase the exposure of J(x) for display.

Dehazing of Distant Region

Images taken under bad weather conditions such as fog, mist, rain and snow suffer from poor contrasts and severely corrupted colors. In bad weather, the radiance from a scene point is significantly altered due to atmospheric scattering. The amount of scattering depends on the distances of scene points from the observer. Therefore, restoring clear day contrasts and colors of a scene from a single image taken in bad weather is inherently under-constrained [1]. If the particles in the atmosphere are small then the transmission *t(x)*is subjected to wavelength(i.e., thin hazing) and the objects are kilometres away. In such situation, the color channels have different transmissions. This is why the appearance of objects is bluish near hjorizon (Fig. 4(b)). As the haze imaging model, the Equation (1) assumes common transmission for all color channels, our above method might fail to recover the true radiance of the distant objects in the scene and they remain bluish.

Thus we proposed a new method to tackle the different transmission among the color channels. Here we estimate the atmospheric light for each color channel independent of the other.

Radiance for each color is calculated independent of the other color channel. Now radiance for these color channels can be used for generating the dehazed image. The whole method can be explained in Fig. 3.

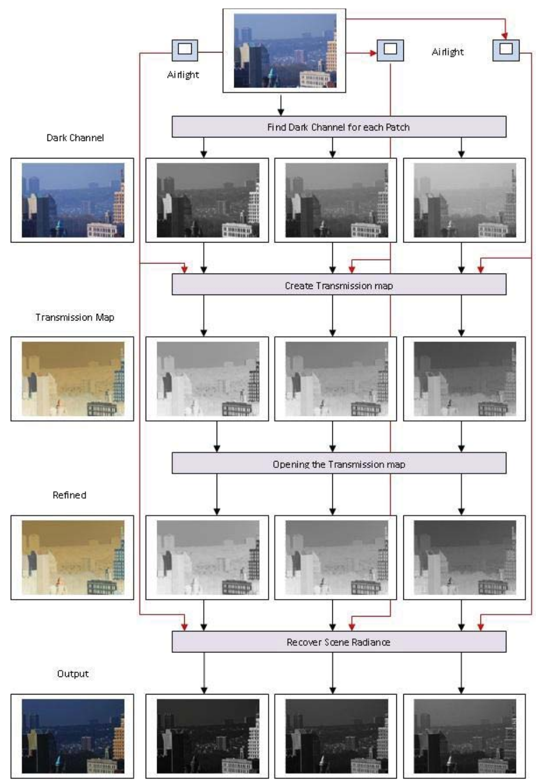


Fig. 3 Process flow chart of improved dehazing method. Patchsize is 3x3

The transmission map is estimated for each color channel independent of other and using the respective atmospheric light for that color channel. Therefore the transmission $t_c(x)$ is given by:

$$t_c(x) = 1 - \omega \left(\min_{y \epsilon \Omega(x)} \left(\frac{I^c(y)}{A^c} \right) \right) \tag{14}$$

where ω is the dehazing parameter. For estimating the radiance we calculate $J_c(x)$ for each color channel using the respective transmission map and atmospheric light for that color channel. Thus $J_c(x)$ is given by

$$J_c(x) = \frac{I^c(x) - A^c}{max(t_c(x), t_0)} A^c \tag{15}$$

Here we can see that the bluish problem is removed here. We can set ω as according to the required transmission for the particular channel. For reducing bluish appearance of distant objects we can set value of ω slightly lower (here we lowered it by 0.05) for blue color channel with respect to other channels.

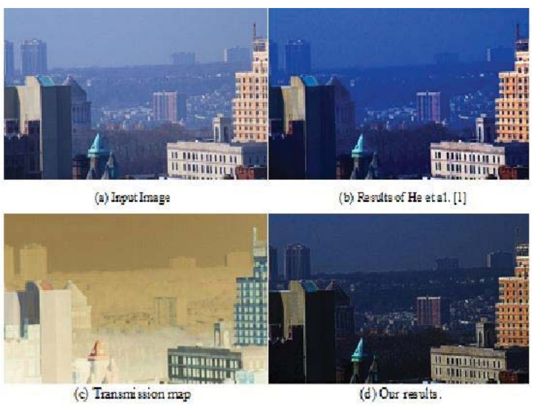
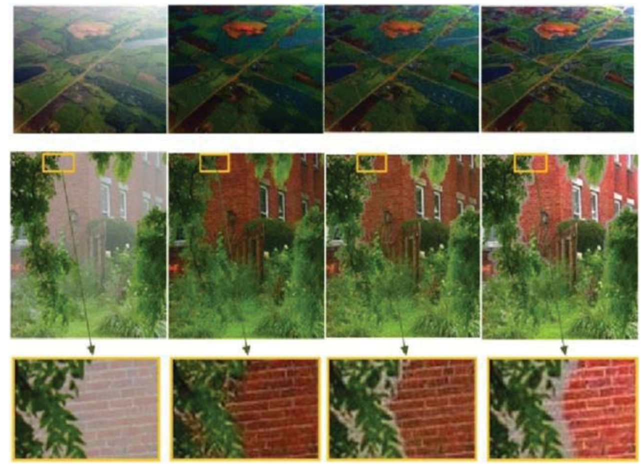


Fig. 4 Haze removal results. Comparison with He et al [6]. results

Dehazing Parameters

Several parameters can be tweaked in order to achieve satisfying dehazing results. First, the patchsize of the dark channel and transmission map is variable. The larger the patchsize is, the more likely it is that the dark channel prior is satisfied(because the probability that a patch contains a darkpixel is increased and thus the larger the patch size, the darker the dark channel). The smaller the patchsize is, the smaller are the visible errors in the dehazed image, especially those along edges but the recovered scene radiance is oversaturated [1]. Fig.5 shows the effects of different patchsizes.

In Fig. 5 we can see the haze removal results using different patch sizes. In Fig. 5(b), the patch size is 3 x 3. The colors of some surfaces look. In Figs. 5(c) and 5(d) , the patch sizes are 7 x 7 and 15 x 15, respectively. The results appear more natural than those in Fig. 5(b). This shows that our method works well for sufficiently large patch sizes.



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

Fig. 5 Recovering images using different patch sizes (after refining). (a) Input hazy images[3]. (b) Using 3 x 3 patches. (c) Using 7x7 patches. (d) Using 15x15 patches.

A second parameter stems from equation (13). The parameter t_0 defines the lowerbound of transmission. When choosing the parameter to be over 100% the application iscapable of adding hazeto the scene. The effects of alterations to $t_0$can be seen in Fig. 6.

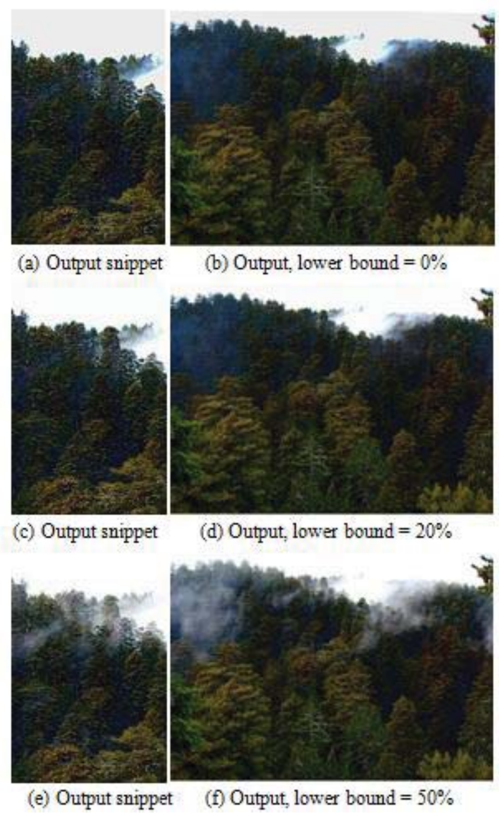


Fig. 6 The effects of increased lower transmission bound

With t_0 being 0% it has been found in some cases, that artifacts are introduced to the dehazed image due to noise.

Also with t_0 = 0%, the sky or other very bright regions are forced to take on a slightly darker colour. Henceforth, choosing a t_0 above zero is also a noise cancelling action.

The third parameter regulates the degree of dehazing, He et al.[1] called that parameter ω, which is a real number between zero and one. It assures that more haze is kept at more distant objects. Reason for its introduction is that completely haze free images may seem unnatural and the feeling of depth may be lost for the viewer due to the effect called *aerial perspective*. Secondly, the physical background of thedark channel prior actuallyassumes an haze free image, however manages to handle certain degrees of noise well. Since the input image is never free of haze, ωhas been found to givereasonable results at about 95% due to testing. The effects of alterations to ω can be seen in Fig. 7 [shown in the last page].

The amount of haze increases as the distance between the viewer and the objects increases. Thus the closer objects in image contain less haze as compared to others. On the basis of color information ω can be made adaptive. The patch which have less haze, ω takes a low value for that patch (less amount of haze is removed) and vice versa. The results can be seen in Fig. 8 [shown in the last page].

Results & Comparison

We have used opening of the transmission map for refining it. Our method can recover the true radiance of the distant objects and problem of bluishness is reduced.

We have compared our approach with Zou et al. work[9]. They have used a method to refine the dehazed image by dilating and eroding it, thus refining block effect and halo effect. However this method leads to blurring of images and details are highly reduced (sharpness reduces).

We have refined the transmission map by eroding and dilating thetransmission map and thus improving the dehazing results. Fig. 9 shows the comparison of our method with Zou et al [9] and we can see that output images from our method are sharper.

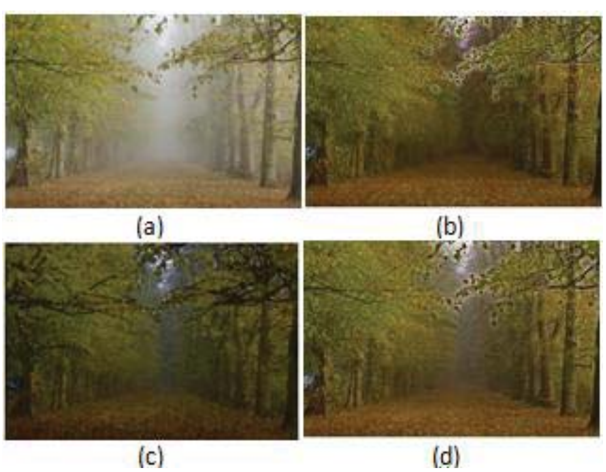


Fig.9 (a)input image. (b) the defogged image using Dark Channel Prior. (c) Zou et al[8] result (d)Our result

Conclusion

The dehazing algorithm presented in this paper shows the improvement in the contrast of haze-degraded images. We refined the transmission map by Opening (eroding and dilating) it. Our method recovers the true scene glow of the remote objects and the problem of bluishness is reduced.

Bilinear or cross-bilinear filter can be applied further for removing block and halo artifacts but the image gets blurred depending upon the σ_s and σ_r parameters of the bilinear filter.

References

[1] Kaiming He; Jian Sun; Xiaoou Tang, "Single Image Haze Removal Using Dark Channel Prior," *Pattern Analysis and Machine Intelligence, IEEE Transactions on* , vol.33, no.12, pp.2341,2353, Dec. 2011.J.ClerkMaxwell,ATreatiseonElectricityandMagnetism,3rd ed.,vol.2.Oxford:Clarendon,1892,pp.68–73.

[2] Yan Wang and Bo Wu. Improved Single Image Dehazing using Dark Channel Prior, 978-1-4244-6585-9/10/$26.00 ©2010 IEEE.

[3] Raanan Fattal, Single image dehazing, ACM Transactions on Graphics (TOG), v.27 n.3, August 2008 [doi>10.1145/1360612.1360671].

[4] Tan, R.T., "Visibility in bad weather from a single image," *Computer Vision and Pattern Recognition, 2008. CVPR 2008. IEEE Conference on* , vol., no., pp.1,8, 23-28 June 2008. doi: 10.1109/CVPR.2008.4587643

[5] S.G. Narasimhan and S.K. Nayar,"Chromatic Framework for Vision in Bad Weather," IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Vol.1, pp.598-605, Jun, 2000.

[6] K. He, J. Sun, and X. Tang. Single image haze removal using dark channel prior. In IEEE Conference on Computer Vision and Pattern Recognition (CVPR'09), pages 1 956-1963, 2009.

[7] S. G. Narasimhan and S. K. Nayar. Vision and the atmosphere. IJCV, 48:233-254, 2002.

[8] Chengming Zou and Jinrui Chen. Recovering Depth from a Single Image Using Dark Channel Prior, ACIS International Conference, 2010.

[9] R.C.Gonzalez. Digital Image Processing Using MATABLE, Prentice Hall Upper Saddle River, New Jersey, 2002

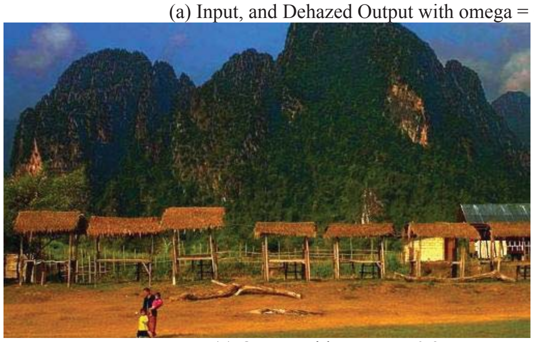
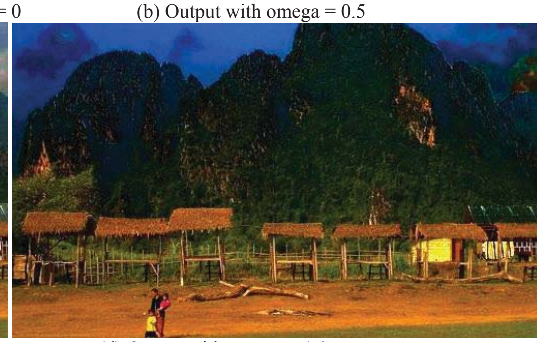
[10] He,K.,Sun, J. and Tang, X. (2010) "Supplemental Materials" http://personal.ie.cuhk.edu.hk/~hkm007/cvpr09/.

[11] http://www.minigreenhousekits.com

[12] http://static5.businessinsider.com

[13] http://www.enclosureguy.com


(a) Input, and Dehazed Output with omega = 0 (b) Output with omega = 0.5

(c) Output with omega = 0.9 (d) Output with omega = 1.0

Fig.7 The effects of decreased ω to the output image.

Fig. 8(a) Input hazy image. (b) Output image with fixed ω. (c)Output image with adaptive ω