Development of Defogging Algorithm for Image

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***Abstract*—Haze removal algorithm using dark channel prior (DCP) is an effective approach to recover haze-degraded images. However, the output images can sometimes have dim colour thus lose contrast & colour information. In this paper, we proposed an improved defogging algorithm based on DCP. By applying guided filter and multi-scale image fusion, we are able to combine the relevant information from several derived inputs together to restore a hazy image. Experiments show that this enhanced method improves the quality of output images in the case of mild haze and rather great scene depth. The output images not only are more visually-pleasing to naked eyes, but also provide more details to computer vision applications.**

Keywords-component: haze-degraded image; defogging algorithm; dark channel prior; Contrast Limited Adaptive Histogram Equalization (CLAHE); guided filter; Laplacian pyramid decomposition; image fusion

I. Introduction

Outdoor images are usually degraded due to the presence of haze, mist, smoke and other atmospheric phenomena [7] ,resulting in a loss in both colour and contrast of the images.

Figure 1. An example of a haze-degraded image of Singapore

The degradation can be explained as the combined result of atmospheric attenuation and the veiling effect of the airlight [6]. Atmospheric attenuation is the process in which light energy decreases due to absorption or scattering by the atmosphere with an increasing distance from the light source. The veiling effect of airlight is the phenomenon that light is scattered into the line of sight by atmospheric particles.

Haze removal algorithms are employed in order to improve the visibility of haze-degraded images which have colour shift and poor contrast. The enhanced visibility not only makes the images more visually pleasing and easier to read, but also can improve the performance of computer vision applications like feature detection and object recognition which requires accurate outline / edge information.

Several haze removing algorithms have been proposed so far. Polarization based methods were introduced and developed by Y. Y. Schechner [8, 9]. By using more than one input images of the same scene taken under different weather conditions, additional information is obtained to restore the degraded image. Depth based methods [10, 11] , instead, require additional inputs of geographical information. By uploading 3D models of the scenes or using interactive algorithms, these methods can estimate the rough depth information that is used to recover the degraded images. However, these methods are limited as they require multiple inputs with many restrictions, making the defogging algorithm unpractical in some situations and unsuitable for automation.

The very recent haze removal algorithm using dark channel prior (DCP) is an effective and efficient method[1]. In this project, in addition to the state-of-the-art defogging algorithm using DCP, we propose a few more steps to further enhance the quality of the results produced. By applying a guided filter and image fusion on the output images processed by the DCP method, our method generates images with better colour information and more details.

II. Background & Related Work

The widely-used image degradation model to demonstrate the formation of a haze-degraded image is computed as follows [1, 8, 12]:

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

where *I* represents the intensity observed, *J* represents the scene radiance, *A* represents the estimated atmospheric light, and *t* represents the medium transmission that is proportional to the scene depth. *J(x)t(x)* represents the direct attenuation of light and *A(1-t(x))* represents the airlight. Under the assumption that the haze is homogeneous, *t* can be expressed as:

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

where β is the scattering coefficient and *d* is the scene depth. It can be deduced from Equation (2) that the bigger the scattering coefficient (i.e. the denser the haze), the smaller the medium transmission. From Equation (1), we can then deduce that the direct attenuation will be smaller while the airlight will be greater.

Therefore, to restore a haze image , the haze-free image J restored can be calculated given medium transmission *t* and global airlight A .

2.1. Dark channel prior

Single image defogging using DCP has made significant progress in recent years. It started with the research done by K.He, J.Sun and X.Tang. In their paper [1] they proposed the dark channel prior to remove haze from a single input image.

A. Estimating the transmission

Based on observation, in most of the outdoor non-haze-degraded images, the non-sky regions have low intensities in at least one colour channel (out of the Red, Green and Blue colour channels) due to the presence of dark or colourful objects. It can be shown as:

$$J^{dark}(x) = \min_{c\in\{r,g,b\}} (\min_{y\in\Omega(x)} (J^c(y))) = 0, \qquad (3)$$

where J^{dark} is the dark channel of image *J*, *c* represents the colour channel and *Ω* is a local patch centered at *x* .
Thus, from Equation (1) and Equation (3) it can be deduced that

$$\min_c (\min_{y\in\Omega(x)} \frac{(I^c(y)}{A^c})) = \tilde{t}(x) \min_c (\min_{y\in\Omega(x)} \frac{(J^c(y)}{A^c}) + (1-\tilde{t}(x)), \qquad (4)$$

where $\tilde{t}$ is the medium transmission in a local patch and A^C is the atmospheric light which is assumed as a constant.
According to Equation (3), LHS of Equation (4) is 0. Thus,

$$\tilde{t}(x) = 1 - \omega \min_c (\min_{y\in\Omega(x)} \frac{(J^c(y)}{A^c}), \qquad (5)$$

where *ω* is a parameter to preserve some haze for the distant objects to create a sense of increase in scene depth.

As shown in Equation (5), the transmission map can now be calculated given the colour haze image J^c and the atmospheric light .

B. Refining the Transmission Map Using Guided Filter

The transmission map calculated in section A is then refined using a guided filter [14] in order to capture and preserve the edges of objects in the image. The guided filter will be explained later in section 2.2.

C. Recovering the Scene Radiance

Using the image degradation model, haze-free image J can be recovered as:

$$J(x) = \frac{I(x) - A}{\max(t(x), t_0)}, \qquad (6)$$

where t_0 is a lower bound set so that when $t = 0$, $J(x)$ can still be defined instead of being prone to noise. However, this means that some amount of haze is preserved.

D. Estimating the Atmospheric Light

The atmospheric airlight is calculated by first picking the top 0.1% brightest pixels in the dark channel as they are haze-opaque, meaning their high intensity is due to haze instead of the colour of the object itself. Among these pixels, the pixel with the highest intensity (closest to 1) is selected as the atmospheric light.

2.2. Guided filter

Guided filter [14] is an edge preserving smoothing filter which is effective in providing edge information and at the same time, efficient in computation. It requires two input images and generates an output image q that can transfer the structures of the guidance image I to the filtering output. The model of the guided filter is shown in [14] as follows:

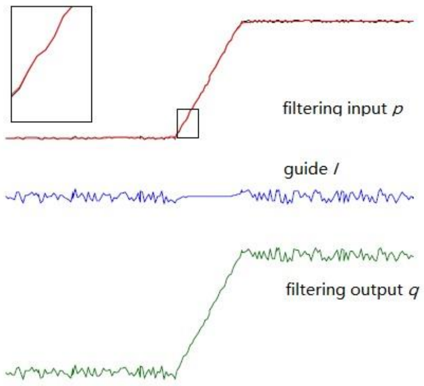

Figure 2. A simplified model used to explain the effect of a guided filter.[14]

The output is calculated as follows:

$$q_i = \sum_j W_{ij}(I) p_j , \qquad (7)$$

where *i* and *j* are indexes of pixels and *p* is the filtering image. W_{ij} is the filter kernel that is independent of *p*. It is calculated by:

$$W_{ij}(I) = \frac{1}{|\omega|^2} \sum_{k:(i,j)\in\omega k} \left(1 + \frac{(I_i - \mu_k)(I_j - \mu_k)}{\sigma_k^2 + \epsilon}\right) \qquad (8)$$

From Equation (7) we can conclude that *q* and *I* are linearly related, meaning that the output *q* will have an edge only when I has an edge. As shown in Figure 2 [14], the output image is produced by transferring the structure (edge discontinuity) of the guidance image *I* to the filtering input *p*.

2.3. Multiscale Fusion Process

Two (or more) images are combined together by fusing the inputs with their weightages. This is calculated by:

$$R(x, y) = \sum_{k=1}^{K} \bar{w}_k(x, y) I^k(x, y), \qquad (9)$$

where I^k represents the input, $\overline{w}_k$ represents the normalized weight map which satisfies $\sum \overline{w}_k = 1$.

Multi-scale Laplacian Pyramid decomposition [15] is a classical yet efficient image fusion technique. An input image g is first convolved by a Gaussian kernel to down-sample its size from. If we assume the size of the original image g_0 is $(2N+1)*(2N+1)$, then the filtered output image g_1 has a size of $(2N-1)*(2N-1)$. As illustrated in Figure 3, each time when the input is down sampled, its size is reduced. If the process is iterated, the size of the output image g_i can be denoted as $(2^{N-i}+1)*(2^{N-i}+1)$.

A Gaussian pyramid is generated by iterating two steps: the down sampling process and a low pass filter which removes undesired noise to smooth the down-sampled image. In the process of smoothing, the edge information is taken away.

The Laplacian pyramid, instead, saves the difference between image g_i and g_{i+1} to store the edge discontinuity lost in the down-sampling process. Figure 3 lower image is an example of outputs generated in a Laplacian pyramid.

By iterating the process, the inputs decomposed can form a pyramid by applying the Laplacian decomposition to different scales. At the same time, a Gaussian pyramid is computed for each normalized weight map $\overline{w}$.

The inputs are then fused together at each level of the pyramid to generate the output by summing all fused inputs as follows:

$$R^l(x,y) = \sum_{k=1}^{K} G^l\{\overline{w}_k(x,y)\}\, L^l\{I^k(x,y)\}, \quad (10)$$

III. Proposed Algorithm

As compared to other state of the art defogging algorithms, DCP performs especially well in recovering objects in the distance. However, the output images can sometimes be too dim while other methods like Contrast Limited Adaptive Histogram Equalization (CLAHE) can sometimes yield outputs with better contrast information when the scene depth is small and the hazy is thin (scattering coefficient is small). Therefore, by combining relevant information together, we can improve the quality of images processed by dark channel prior.

In this section, we propose an enhanced version of the defogging algorithm on the base of the DCP algorithm. In this method, an input image undergoes white balancing and CLAHE to enhance its colour and contrast. After which, a guided filter is applied on the enhanced image The final output is obtained by fusing the result image with DCP output to improve the visibility of distant objects. Experiments show that this method can enhance the quality of images recovered as compared to outputs produced using the original DCP algorithm only.

3.1. White balancing & Contrast Limited Adaptive Histogram Equalization

White balance [16] adjusts the colour of an image by stretching the Red, Green and Blue channels separately. By discarding the top m% and bottom n% of the pixels in the image and stretching the remaining range as shown in Figure 4, white balance can correct the possible colour inaccuracy of haze image caused by sandstorm or sunset glow. Figure 5 is an example of operating white balance on an input haze image that has an orange colour tone. The output colour is shifted to blue / gray, which is more accurate considering the possible haze-free image.

Figure 3. the input image and the output image after white balancing.

Figure 4. input image and the output after CLAHE

We then apply CLAHE to the white balanced image. A CLAHE–based method proposed in [17] converts RGB image into HIS before calculating the intensity information. As shown in Figure 6, this method effectively enhances the contrast of the input, producing images with rich details, which are essential in providing edge information in the next section.

3.2. Guided filter

The DCP output and CLAHE output are the two input images when applying the guided filter. DCP being the guidance image and CLAHE being the filtering input image, the edge information of DCP is preserved while most of the colour information in CLAHE is preserved when the output image is produced. The guided filter enhances the detail of objects with small scene depth. In addition, the DCP output is sometimes very dim. The filtered image also improves the visibility of dark objects in the image.

By comparing the three images displayed in Figure 7, it can be seen that after a guided filter is applied to DCP output 7(b), the result 7(c), the buildings have higher intensity and greater contrast. The tree leaves near the camera also contains better details.

(a) (b) (c)

Figure 5. the input image, the DCP output and the filtered output

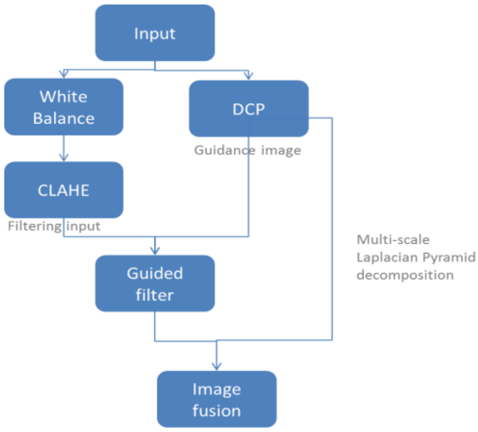

Figure 6. a flow chart of the proposed method

3.3. Image fusion

Multi-scale Laplacian Pyramid decomposition is performed at this stage to enhance the visibility of distant objects. Our method requires two inputs for fusion: the DCP output as well as the guided filter output.

The refined transmission map T calculated when processing using DCP is used as the weightage for the guided filter output, while weight map (1 - T) is assigned to the DCP output (weight maps T and 1- T are shown in Figure 8 Row 3). As T is proportional to scene depth, the further the object, the higher the confidence of the DCP image. As the result, objects with small scene depth gain more information from the guided filter output as it contains more edge information and better colour performance. Objects with great scene depth gain most of the information from the DCP output as the histogram equalization can fail to obtain contrast information when the haze the rather dense due to the long distance from the camera, while the DCP can sometimes recover more information due to its well refined transmission map.

By comparing the original input and the final output in Fig.8 row1, the result produced by our method has recovered rich information for both nearby and distant objects. The output is produced by fusing (1) the image operated by white balance, CLAHE and then guided filter (Fig.8Row2left) with a weightage of T (Fig.8 Row 3 left), and (2) the image processed using DCP (Figure 8 Row 2 right) with a weight map calculated by (1 - T).

Figure 7. (a) guided filter output from section 3.2; (b) DCP output; (c) weight map for (a) in image fusion (section 3.3); (d) weight map for (b) in image fusion (session 3.3)

Figure 8. comparison between the original hazy image and the output produced by our method in section 3.3

IV. Experiment Results

By comparing the outputs shown in figure 9, we can conclude that the proposed method produces output images that are more visually pleasing with better edge information. The results produced have better contrast for objects near the camera as well as in the distance.

Comparing (b) and (c), we can conclude that images recovered by white balance & CLAHE have clear edge discontinuities. However, the colour of (b) is close to (a), showing that it cannot effectively restore colour information while (c) produced by DCP is shown to be able to recover object with large scene depth that cannot be recovered by CLAHE when the haze is rather dense.

However, by putting (b) and (c) together, it is clear that the DCP outputs are more dim in colour making it visually less pleasing and harder to recognize the edges of dark objects like shades, trees and dark-colour buildings. Therefore, by using our method, a guided filter is applied with (b) and (c) being the two input images. The output of this step obtains most of its colour from (b) and contrast from both (b) and (c). (d) is produced, which has better colour and contrast for objects with small scene radiance. However, if the haze is rather heavy, distant objects like buildings near the sky region are recovered better when DCP is applied. Therefore, there is a need to conduct the last step in our method, which is to fuse DCP with the filtered image (d).

By compare the results (e) and (d), we can observe that images in (e) are clearer in showing the distant building as weightage

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

Figure 9. Comparison of the several outputs. (a) original haze images; (b) results of applying white balance and CLAHE; (c) DCP output; (d) results after applying guided filter; (e) final outputs after applying image fusion.

assigned to (c) in the fusion process is high in regions with large scene depth.

However, the sky regions in (e) compromise some accuracy by using information from DCP, as the sky regions in DCP are distorted. The distortion can be reduced by changing the values of parameters like t0 and ω but cannot be completely eliminated. And there is no current algorithm that can be used to effectively decide the values of the parameters. But this can be improved as long as any future defogging algorithm using dark channel prior improves the quality of sky regions in its output.

V. Conclusion & Future Work

Haze images can be recovered by various defogging algorithms to enhance its colour and contrast. In this project, we developed the current defogging algorithm using DCP further by applying techniques including white balance, contrast limited adaptive histogram equalization, guided filter, Laplacian pyramid decomposition and image fusion. By applying these additional steps, we are able to generate outputs that have better colour performance and more edge discontinuities. As shown in our experiment results, the developed algorithm is effective in enhancing performance for images with mild haze and large variance of scene depth.

In the future, this method can be improved further by replacing the sky regions in DCP by sky regions produced by CLAHE to improve the performance of this method in sky regions. What is more, we can also improve the computational efficiency by simplifying the code used to process images so that it can be applied in real-life applications.

Acknowledgment

I would like to thank Nanyang Technology University and Anderson Junior College for the opportunity to participate in this project. I want to express my appreciation of Professor Lap-Pui Chau and my research mentor Jie Chen for their kind support and guidance in the last eight months. And I appreciate the help and understanding of my school teachers-in-charge Mdm Resma and Mr Peh Kar Liang throughout the programme.

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