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Research on Enhancement Technology on Degraded Image in Foggy Days

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Abstract: Fog may affect transportation, video monitoring, target tracking and even military activities. Therefore degraded image enhancement in foggy days has great application value and academic value. In this study , image defogging method based on image enhancement is discussed first. Then different algorithms for image restoration are implemented based on the model of degraded images in foggy day. The experiment result shows that the guided filter algorithm for images defogging is better than other methods in image defogging.

Keywords: Guided filter, histogram equalization, image enhancement, image defogging

INTRODUCTION

Fog is a common natural phenomenon. Even in the sunny summer, mist may appear due to water evaporation on the surface. Fog is also a disastrous weather, because it will affect road transportation, aviation and navigation, power systems, industrial and agricultural production as well as people's everyday lives in different degrees. In recent years, with the development of computer hardware and software technology, defogging images from foggy weather has become possible (Wan *et al*., 1999). In foggy circumstances, because of degraded visibility, image characteristics like contrast and color are weakening. When analyzing image information in security monitoring, high-speed transportation or military activities, blurred images or images losing details may cause potential safety hazard. In fact, image defogging is an important part of computer vision. Its main application is video monitoring topographic survey and automated driving (Jobson *et al*., 2002).

Currently, image defogging methods can be divided into two categories, image enhancement (non-model algorithms) and image restoration (model algorithm).One is based on image enhancement, enhancing image contrast to get sharp images. The other is image restoration method based on physical models, modeling meteorological conditions and restoring images on the basis of these models (Chavez, 1988).

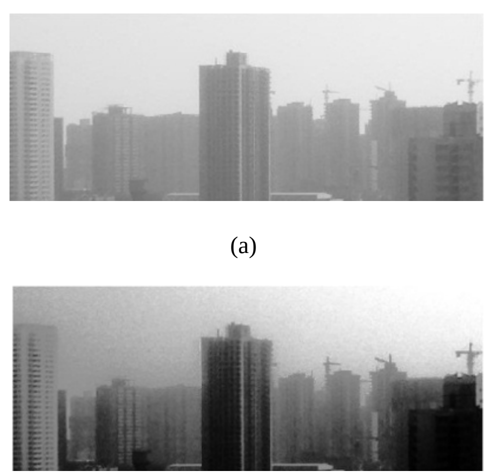
In this study, we proposed a guided filter algorithm for images defogging, comparing with other methods in image defogging, the guided filter algorithm is better and more effective.

IMAGE DEFOGGING METHOD BASED ON IMAGE ENHANCEMENT

Due to the scattering of light in the fog air, the contrast and brightness of the degraded image is not very ideal. The basic idea of histogram equalization is to map the gray level values of the original image so that the probability density of the gray level values of the transformed image is uniformly distributed. The equalized image becomes a gray scale image of uniform distribution. This means that the dynamic range of the gray scale image has been expanded, thereby enhancing the image contrast.

Global histogram equalization: Histogram equalization can improve the contrast of foggy images, thereby increasing the resolution. The experimental results of global histogram equalization algorithm processing foggy images are shown in Fig. 1 and 2.

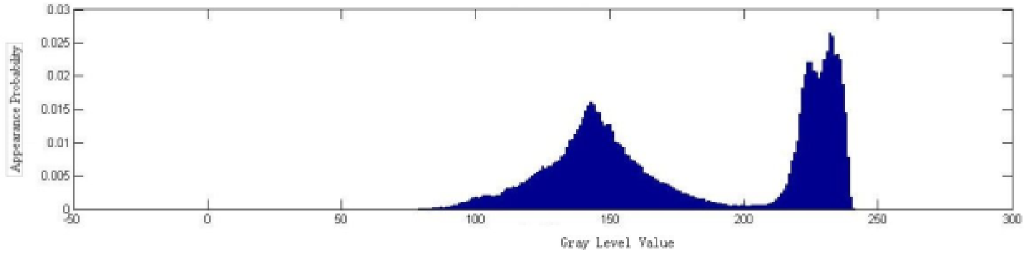
This method is fast. But it is easy to see from Fig. 1 that although the contrast of the image has been enhanced, certain details of the image are ignored. The enhancement effect is not very ideal. The results vary as



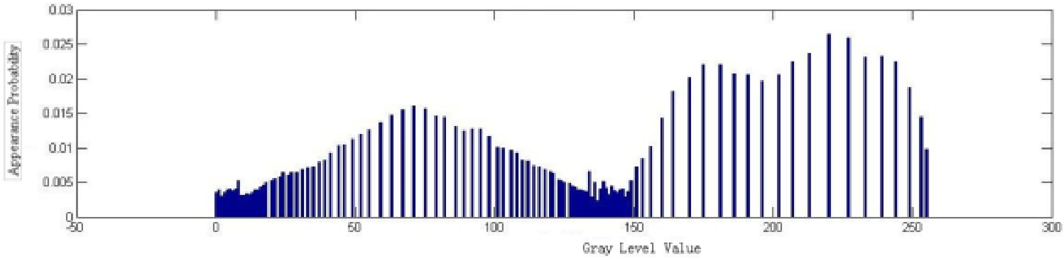
(a)

(b)

Fig. 1: Results of global histogram equalization; (a) Original, (b) image after processing



(a)



(b)

Fig. 2: Histograms before and after processing

the depth of field changes and the ideal effect can be achieved only in a very small depth of field (Oakley and Satherley, 2009). Therefore local histogram equalization is taken into account for processing foggy images.

Local histogram equalization: The key of local histogram equalization is to divide image into multiple local areas, then calculating histogram equalization for each area, finally adding up calculation results (Wen *et al*., 2008). The advantage of this method is that it guarantees the normal enhancements meanwhile gets darker areas nearby a good enhancement processing. The image quality after local histogram equalization processing is better than global histograms. The experimental results are shown in Fig. 3 to 7.

From the above analysis it is easy to find that when the parameter remains constant while the window size varies (Fig. 4 and 6), the smaller the window size is the sharper the image is. When the window size remains constant while the parameter varies (Fig. 4 and 5), the greater the parameter is the greater the image contrast is. While the parameter is selected too large, the contrast enhancement going too far makes parts of the image information lost (Fig. 7).

Local histogram equalization algorithm has the advantage of greatly improving the contrast of every small area of an image, while the disadvantage is that some areas are enhanced incorrectly so that the image looks not natural. Just like the global histogram equalization it still can't remove the weather affection from distant scenes in the image (Chen *et al*., 2008). And the algorithm is complex so the computation is heavy and the program runs more slowly.

Fig. 3: Original image before processing

Fig. 4: Image after processing (window 40, parameters 0.1

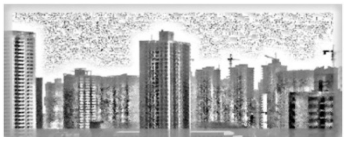


Fig. 5: Image after processing (window 40, parameters 0.5)

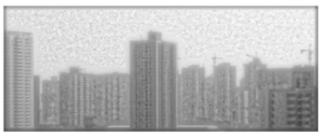


Fig. 6: Image after processing (window 20, parameters 0.1

Fig. 7: Image after processing (window 20, parameters 0.9)

Fig. 8: Original image before processing

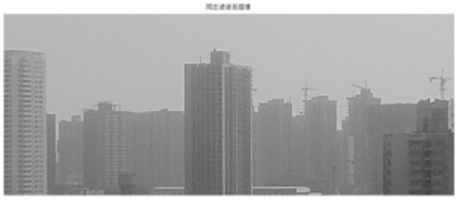


Fig. 9: Image after homomorphic filtering

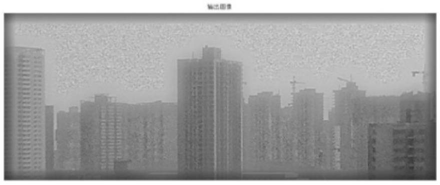


Fig. 10: Image after processing (window 40, parameters 0.1)

Fig. 11: Image after processing (window 40, parameters 0.5)

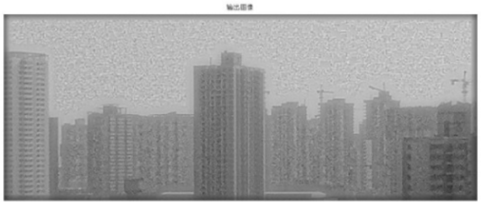


Fig. 12: Image after processing (window 20, parameters 0.1)

Fig. 13: Image after processing (window 20, parameters 0.9)

Improved local histogram equalization: Simple histogram equalization can make the image enhanced incorrectly, thus taking a filter into account to remove weather effect from the image before using local histogram equalization. When the weather effect is removed, the incorrect enhancement is reduced, so the image contrast becomes acceptable (Sengee and Heung, 2008). The experimental results are shown in Fig. 8 to 13.

We can see from the results that when the parameter remains constant while the window size varies (Fig. 10 and 12), the smaller the window size is the sharper is the image. When the window size remains constant while the parameter varies (Fig. 10 and 11), the greater the parameter is the greater the image contrast is. But the contrast enhancement is going too far thus introduces larger color distortion to the image. When the parameter is selected too large (Fig. 13), the contrast of the gray scale image is too great which results in loss of detail.

When local histogram equalization is used after homomorphic filtering, its recovery effect is better than direct histogram equalization, because filter can improve defogging effect. But without estimating degradation model depth of field effect cannot be well solved. Neither local histogram equalization nor improved local histogram equalization algorithm can remove weather effects in the distance (Edwin, 2010).

Image Defogging Based on Multi-Scale Retinex (MSR): Image defogging based on Retinex theory is research hotspot in recent years; algorithms also vary (He *et al*., 2009). In this study center surround Retinex algorithm is selected for analysis which has been developed rapidly in recent years.

MSR algorithm uses different scales of δ for linear weighted average on the basis of Single Scale Retinex (SSR). The formula can be expressed as following:

$$R(x,y)=\sum_{i=1}^{k} W_i \left\{\log I(x,y) - \log[I(x,y) * F_i(x,y)]\right\} \tag{1}$$

where,

k = The total number of the scales of δ

W_i = The weight satisfying the identities $\sum_{i=1}^{k} Wi = 1$.

Generally, MSR takes three scales, that is $k = 3$. $F_i(x, y)$ is the Gauss function of which the parameter is δ_i. From Eq.1 we can see that MSR algorithm improves image enhancement effect by linear weighted averaging multiple fixed scales of SSR. The experimental results are shown in Fig. 14 and 15.

From Fig. 14 and 15 we can see that the color of image becomes brighter after MSR processing and looks more real. So MSR is superior on image color restoration. But the shortcomings of the MSR are also very obvious. Because the parameter estimations are not accurate, the enhancement effect is not ideal and

Fig. 14: The MSR original image

Fig. 15: Image after MSR processing

fog still remains in the distance of the image (Jobson *et al*., 2007).

To sum up, the first method based on image enhancement cannot remove weather effects in the distance of the image. That is, simple image enhancement method cannot handle depth of field effect. So we turn to the second image defogging method based on physical degradation model.

IMAGE DEFOGGING BASED ON PHYSICAL DEGRADATION MODEL

Image restoration based on blackbody theory: According to the physical characteristics of light transmission in the fog, optical model of the foggy image can be described as following. This model is widely used in image defogging techniques research:

$$I(x,y) = e^{-\beta d(x,y)} J(x,y) + (1 - e^{-\beta d(x,y)})A \tag{2}$$

The first polynomial of the right part in Eq. (2) is direct attenuation, which represents attenuation of scenes radiation rate in the media. The second polynomial is air light, which represents the offset of scenes color caused by global atmospheric light scattering (Levin *et al*., 2010). Detail is as following.

I is the input image, J is the image in good weather conditions and A is sky brightness, which is selected independently of pixel position (x, y) (Tamar *et al*., 2008) β is the scattering coefficient of air, which mainly represents the scattering capacity of light on unit volume of air and d is depth of field.

Eq. (2) can be further written as:

$$J(x,y) = e^{\beta d(x,y)}[I(x,y) - (1 - e^{-\beta d(x,y)})A] \tag{3}$$

We can see that degradation degree of pixel selection is exponentially related with depth of field of the pixel point from Eq.3. The traditional recovery methods ignore the depth of field effect to restore the

(a) (b)

Fig. 16: Effect comparison 1; (a): Original; (b): Image after processing

(a)

(b)

Fig. 17: Effect comparison 2; (a): Original, (b): Image after processing

image, not taking full advantage of prior knowledge of degradation, thus cannot remove effects of harsh meteorological factors in degraded image. The experimental results are shown in Fig. 16 and 17.

Images defogging based on guided filter: From the above analysis we can see that in addition to the effect of the atmospheric scattering, the most important factor affecting the foggy image restoration is the depth of field effect. Hence, how to deal with the depth of field would be the key to remove weather effects of the image (Qing and Ward, 2011). Image defogging based on guided filter selects clearer parts from the guided image for preliminary process to get some recovery parameters, it then processes the image using recovery formula.

First we define a general process of linear filter transform. If the guided image I and the input image p are both known, the output of pixel filter q can be expressed in a form of weight average as:

$$q_i = \sum_j W_{i,j}(I) p_j \tag{4}$$

Guided filter for image smoothing is to use the filter function $W_{i,j}$. Guided filter is not only a smooth operator, but also a very good gradient calculation process. It is a new application of guided filter.

Fig. 18: The original image

Fig. 19: Image after filtering

Fig. 20: Image after processing

Gradient computation comes from a local linear model. The closed global optimal solution will be found through locally optimal calculation by guided filter for each window. This method can be expressed as:

$$E(a) = (a-\beta)^T \Lambda (a-\beta) + a^T L a \qquad (5)$$

where, α and β are global position matrix, L is N×N gradient operator, Λ is the constraint of diagonal matrix coding and the overall. The solution of Eq. (5) can be simply expressed as $(L + \Lambda)\ \alpha = \Lambda\ \beta$.

If β is a reasonably estimated mask, we can run a Jacobi calculation to obtain an approximate solution. This algorithm is using the above properties of guided filter to defog images (Rahman *et al*., 2009). The experimental results are shown in Fig. 18 to 20.

SIMULATION RESULTS

We can see that the result in Fig. 16 is very satisfactory for a single-layer mist and the result in Fig. 17 is ideal for general image defogging. This method can recover the image more accurately for small depth of field area, but for big depth of field area the recovery results are not ideal due to the heavy information loss of the original image caused by increased interference. From a computational point of view, the algorithm is complex. If the image is too large, the running time of the program will be significantly increased and the program may cause memory overflow (Tan and Oakley, 2010). Although this method is theoretically feasible, but in practice there are many problems to be solved.

The effect of fog has been removed in Fig. 19. From Fig. 20 we can see that defogging method based on guided filter is able to defog images with large depth of field. The restoration effect is satisfactory and the program runs fast.

CONCLUSION

In this study we focus on two types of image defogging algorithm, image enhancement and image restoration. From the experimental results we find that algorithm based on image enhancement has relatively fast processing speed, but still many problems exist. Because the degradation information is not efficiently used, the recovery result is unstable. Defogging method based on image restoration takes full advantage of degradation model, so its experimental results are better than the results of the image enhancement. Starting from the degradation model of foggy image, we deduct the corresponding formula and ultimately draw the conclusion that the depth of field causes the foggy image degradation. For the depth of field in the image, we consider using blackbody theory to ignore factors except the depth of field. We find that this method can handle smaller depth of field effect, the algorithm is complex and the processing speed is slow. Taking into account that filtering can be used to handle foggy weather effects, we use filtering algorithm to get the coefficient of image degradation. The model algorithm is improved by using guided filter to obtain the basic information of the fog in the image. From this information we use appropriate model to get degradation coefficient and apply it to image defogging. The recovery effect is satisfactory.

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