A Fast Algorithm for Image Defogging

Xiaoyan He[1], Jianxu Mao[1], Zewen Liu[2], Jiujiang Zhou[1], and Yajing Hua[1]

[1] College of Electrical and Information Engineering, Hunan University, Hunan, China
{wz6521,mao_jianxu}@126.com
[2] College of Computer Science and Electronic Engineering, Hunan University, Hunan, China
lzewen106@163.com

Abstract. In smoke and haze environment, images acquired by vision create serious distortion or degradation. Obtaining some inaccurate information from an unclear vision, it will have some bad impacts on outdoor activities. More and more common in recent years, the haze phenomena need to be further research. According to the images analysis of the atmospheric degradation model, this article puts forward the improved algorithm based on dark channel prior and morphology. Given the application of He's algorithm to defog, it makes brightness reduce. Therefore, the article firstly proposes to increase the brightness of image before processing, and then estimates the global atmospheric value, the initial transmission rate and the haze density using morphology method, finally substitutes into the simplified model to get the haze-free image. The experimental results show that the proposed algorithm can recover effectively and quickly degraded images. Meanwhile, this algorithm can keep the detail edges of images.

Keywords: Image defogging, dark channel, atmospheric light, morphology.

1 Introduction

Accompanied by the rapid development of intelligent transportation and machine vision, computer vision system has been widely applied in various fields, such as video surveillance system, road traffic driver assistance system, space cameras and medical equipment and so on. However, the current computer vision system has not yet been fully mature, so there are still some problems to be solved. When environmental factors are relatively poor, like fog, haze and other weather conditions, these images collected by computer vision system appear serious degradation, and thereby this phenomenon will have bad effects on the intelligent transportation system to obtain accurate information.

Currently, the image restoration methods are mainly the following two categories: physical and non- physical model approach [2]. Physical model approach is to explore the physical process of image degradation, and build their degradation model, then obtain the best estimate of the value of the image without fog to improve the quality of the image through solving the reverse process of lowering the quality. Non-physical

S. Li et al. (Eds.): CCPR 2014, Part II, CCIS 484, pp. 149–158, 2014.

model approach is to ignore the physical causes of image degradation, whose main purpose is to correct the image color and enhance image contrast.

In recent years, haze removal algorithms for single image have been making significant progress. Relative to the foggy images, Tan [3] considers a haze-free image must have a higher contrast ratio compared with the input hazy image and he removes haze by maximizing the local contrast of the restored image. And then he uses the random (MRF) model to further normalize the results. The method can maximize the recovery images details and structure, which is applied in certain scenes to get better results. However, because this method disconnects from the physical model, and as to the higher saturation of the image itself, it is prone to distortion and color saturation easily. Furthermore, the results appear cavity defects in the area of the local depth discontinuity.

Fattal [4] using a simple model based on physical laws, proposes the method based on ICA. This method firstly assumes that the reflectance of the local small square is constant matrix. Secondly, it assumes that the surface reflectance and transmission in a small square is independent, and the reflectance direction can be estimated by ICA. Finally, using MRF model to infer the color of the entire image, the method can produce a clear and natural image and an effective depth chart. But given the limitations of the method model, heavy fog images cannot get a better processing result. Meanwhile, as to the method based on the color statistic, the method cannot apply for the gray-scale image, and usually it is not difficult to handle the heavy fog area without color.

Based on dark channel prior, He et al [5] proposes a dark channel prior to image foggy algorithm. This method presents a clear of image except sky region which has low intensity values at least one channel in RGB color channel. In hazy image, dark channel intensity values are mainly composed of air light. The method directly uses dark channel to estimate transmission map, and employs soft matting to refine it. The method for outdoor images has achieved good results, but for some light areas, the results will distort. In addition, the big question is that soft matting can consume large amounts of memory and computation time, which real-time requirements cannot be met. Thus, this method cannot be widely applied in computer vision system in practice.

Therefore, for the defects of the conventional defogging algorithms to single image, this article presents a fast algorithm based on dark channel prior and morphology. This article aims to guarantee a certain defogging effects, and tries one's best to reduce the complexity of the algorithm so that it can make defogging speed meet the requirements of real-time application system. Based on the analysis of atmospheric foggy image degradation model, the proposed method firstly enhances image brightness and contrast before restoring image, and then uses dark channel prior to obtain the global atmospheric light values of each channel through acquiring the coordinates of the largest and least piece of the original image, and the initial transmission rate, meanwhile estimates the haze density through morphology method, which can be effective to obtain the haze density and keep the edges of images. Finally the foggy images have been restored.

2 Atmospheric Degradation Model and Dark Channel Prior

2.1 Atmospheric Degradation Model

Scattering is the main factor of image degradation phenomena in harsh environments, such as fog, haze, smoke. In 1975, the atmospheric scattering model is proposed by McCartney, the formula is as follows:

$$H(x) = F(x)e^{-rd(x)} + A(1 - e^{-rd(x)}) \tag{1}$$

where x is the spatial coordinates of the image pixel, $H(x)$ is the observed haze image (that is going to be defogged), $F(x)$ is the resulting image after defogging, $d(x)$ is the depth information of the object on coordinates x, r is the atmosphere scattering coefficient, A is the global atmospheric light, usually, A is generally assumed to be a global constant and independent of the spatial coordinates.

The first part in formula (1) is called direct attenuation. Due to the effects of atmospheric particles scattering, a part of the object surface reflection of light lose because of scattering, scattering part not directly decays exponentially with the increasing of the propagation distance. The second part in formula (1) is called air light. With the increase of the propagation distance, the intensity of air light increases gradually.

Let $t(x) = e^{-rd(x)}$, the formula (1) can be further simplified as:

$$H(x) = F(x)t(x) + A(1 - t(x)) \tag{2}$$

where $t(x)$ means the medium transmission rate describing the proportion between the light which is scattered and that which reaches the camera. Haze removal goal is to recover $F(x)$ from $H(x)$.

2.2 Dark Channel Prior and Estimating the Global Atmospheric Light Rapidly

In the CVPR 2009 Conference, He et al [5] proposes the dark channel prior rule by statistics of the haze-free outdoor images. The rule can be described as: in a certain local area, some pixels value always at least one color channel is very low. In other words, the light intensity value of this region is very small. For an arbitrary image $F(x)$, the dark channel F^{dark} can be defined as:

$$F^{dark}(x) = \min_{c}\left(\min_{y \in \Omega(x)} F^{c}(y)\right) \tag{3}$$

where the superscript c represents three channels R, G, B. F^{c} is a color channel of F and $\Omega(x)$ is a local patch of pixel x. F^{dark} is called the dark primary colors of F, it is low in most cases, and close to zero. The law is called dark primary colors priori through statistical observation.

Generally, in the defogging algorithm of most single image, the value of A is calculated from the pixel containing the fog. In reference [7], the value through artificial selected sky area is treated as the value of the global atmospheric light A. In reference [5], it takes 0.1% of the dark channel input image corresponding to the maximum brightness value as the value of the atmospheric light A. This method is reasonable which has a good result. But the process consumes time relatively. In reference [8] and [9], the magnitude and direction of the global atmospheric light are estimated by space geometry and optimization methods. This method is very complicated, and also requires a strong assumption, so it has a significant limitation. However, this article is to take the brightest pixel of image as the value of the global atmospheric light. This method has some limitations, but its results are still good after taking some experiments. It is most important that the quality can been guaranteed to defog while saving time, which accelerates the processing speed.

2.3 Estimating the Transmission Rate

For the calculation of the transmission rate, firstly it assumes that the transmission rate $t(x)$ is known, the mean value has estimated previously. Taking the minimum operation in the local patch on the haze imaging Equation (2), we have:

$$\min_{y\in\Omega(x)} H^c(y) = t(x) \min_{y\in\Omega(x)} F^c(y) + A^c(1-t(x)) \tag{4}$$

Notice that the minimum operation is performed on three color channels independently. This equation is equivalent to:

$$\min_{y\in\Omega(x)} \frac{H^c(y)}{A^c} = t(x) \min_{y\in\Omega(x)} \frac{F^c(y)}{A^c} + (1-t(x)) \tag{5}$$

And then we take the min operation among three color channels on the above equation and obtain:

$$\min_c(\min_{y\in\Omega(x)} \frac{H^c(y)}{A^c}) = t(x)\min_c(\min_{y\in\Omega(x)} \frac{F^c(y)}{A^c}) + (1-t(x)) \tag{6}$$

According to the dark channel prior, the dark channel value should tend to zero for haze free image, it means:

$$F^{dark}(x) = \min_c(\min_{y\in\Omega(x)} F^c(y)) \rightarrow 0 \tag{7}$$

As A^c is always positive, this leads to:

$$\min_c(\min_{y\in\Omega(x)} \frac{F^c(y)}{A^c}) \rightarrow 0 \tag{8}$$

From equation (8) and (6), we can obtain the transmission rate as follows:

$$t(x) = 1 - \min_{c}(\min_{y\in\Omega(x)} \frac{H^c(y)}{A^c}) \tag{9}$$

where H^c is a color channel of the fog image H .

For the transmittance rate, He et al [5] proposes a method of using soft matting to optimize it, but the computing time is longer.

In formula (9), image defogging thoroughly will make the image distortion, and so the depth information of the image will be lost. Therefore, a coefficient w $(0 < w \le 1)$ is introduced in formula (9) in order to control the amount of the residual fog of defogging image. The finally transmittance rate is modified as:

$$t(x) = 1 - w\min_{c}(\min_{y\in\Omega(x)} \frac{H^c(y)}{A^c}) \tag{10}$$

After obtaining $t(x)$ and A, the defogging image can be calculated according to equation (2) as follow:

$$F(x) = \frac{H(x) - A}{\max(t(x), t_0)} + A \tag{11}$$

where t_0 is used to avoid the overly defogging. A typical value of t_0 is 0.1.

2.4 Estimating the Haze Density Based on Morphological Filtering

It is the key for image defogging to estimate correctly the haze density, while the references [4] and [5] have one disadvantage of high time complexity which is difficult to achieve real-time defogging. Because morphological filtering method has some good effect on keeping image edges in the mutation edges of the scene. In this article, it effectively and rapidly estimates the haze density through morphological filtering instead of using Soft Matting to refine the transmission.

Inflation and corrosion are the two basic operation of mathematical morphology, which are dual operation.

If $f(x)$ is the original image, g is the structural element, so the corrosion of image $f(x)$ is defined as:

$$(f \odot g)(x) = \max\{y : g_x + y \ll f\} \tag{12}$$

Where max is the maximum operation. From the perspective of the geometric decay, the corrosion has shrinkage image effects.

Similarly, the inflation of image $f(x)$ is defined as:

$$(f \oplus g)(x) = \min\{y : (g^\wedge)_x + y = f\} \tag{13}$$

where min is the minimum operation. From the perspective of the geometric decay, the inflation has expansion image effects.

2.5 Specific Algorithm Flow

The specific algorithm implementation process of this method is shown below:

1) Increasing image brightness and calculating the global atmospheric light value;
2) Estimating the initial transmission rate through the results of the dark channel prior;
3) Refining the initial transmission rate by utilizing morphological opening operation;
4) Plugging the refined transmission rate $t(x)$, input haze image $H(x)$ and the atmospheric light A in the formula (11) to obtain the haze-free image.

3 Experiment Results and Analysis

Experimental operating environment is a Windows7 operating system, the CPU of a dual core 2.94GHz, memory of 4GB, using Microsoft Visual C++ 6.0 to simulation algorithm. This article chooses reference [5] to compare and calculate the running time, image information entropy, contrast and mean value to evaluate the superiority of this algorithm.

Through taking the outdoor scene foggy images for experimental test, specific results are shown in the Fig.1, Fig.2, Fig.3. Select three images toys.jpg, train.bmp, forest.jpg, and their size is namely 500*360, 600*400, 1024*768. From Fig.1, Fig.2, Fig.3 can be seen, there is no doubt that the processed images of He's and the method are both better than the original images from the naked eye. Carefully comparing the results in Fig.1, Fig.2, Fig.3, it can find that the proposed algorithm makes the image colors brighter, deeper.

(a) (b) (c)

Fig. 1. The experimental results of toys.jpg. (a) Original Image. (b) He's Result. (c) Improved Method's Result.

(a) (b) (c)

Fig. 2. The experimental results of train.bmp. (a) Original Image. (b) He's Result. (c) Improved Method's Result.

(a) (b) (c)

Fig. 3. The experimental results of forest.jpg. (a) Original Image. (b) He's Result. (c) Improved Method's Result.

3.1 Processing Time

If the algorithm puts into practice, it also needs to take the running time of the algorithm into account, and contrasting with the processing time can be measured to the difference of the computing complexity. The processing time of He's algorithm and the improved algorithm shows in Table 1. It is obvious that the improved algorithm's speed is more quickly than He's.

Table 1. The processing time of He's and the improved algorithm

Images	Size	Processing Time	
		He' s Result/s	Improved Method's Result/s
Toys. jpg	500*360	2. 1800	0. 0366
Train. bmp	600*400	2. 8600	0. 0553
Forest. jpg	1024*768	9. 4740	0. 1394

3.2 Objective Evaluation Index

Currently, objective evaluation index used for degraded image, has primarily three types: full reference, half reference and no reference. Full reference and half reference require a clear image in the evaluation process. However, the article without clear images as reference images has no choice but to adopt no-reference method. Through a series of calculations, the article compares the quality indicators of original images with that of images after processing to evaluate the defogging effects. This article combines standard deviation, mean value and information entropy three aspects to weight on the defogging results. Generally speaking, in the image of each band, because of the haze what has high reflectivity, it increases the overall brightness of the image. If mean value drops over, the method has defogging effects; The size of standard deviation represents the images' resolution. The higher the value, the more the image sharpness; Information entropy reflects the amount of information. If entropy after defogging rises, it shows the image gets more information, and more clearness.

Table 2. Images of the objective evaluation index

toys.jpg	standard deviation	mean value	information entropy
Original Image	38.2991	163.0199	7.0593
He's Result	57.6456	103.7945	7.6194
Improved Method's Result	60.4188	118.0198	7.5980

(a) The Objective Evaluation Index of toys.jpg

train.bmp	standard deviation	mean value	information entropy
Original Image	31.1527	131.4778	6.8739
He's Result	40.7738	80.6517	7.1274
Improved Method's Result	43.1908	83.4126	7.2075

(b) The Objective Evaluation Index of train.bmp

forest.jpg	standard deviation	mean value	information entropy
Original Image	38.1409	118.4333	7.2452
He's Result	41.3120	95.0000	7.2145
Improved Method's Result	42.6026	77.4693	7.0759

(c) The Objective Evaluation Index of forest.jpg

As shown in Table 2 (a), (b), (c), comparing with the values from the table, the improved method reaches a defogging effect to a certain extent. From the datum in Table 2, it shows: standard deviations from the two methods are higher than original image, and it indicates the images after defogging become more clear, and this algorithm's standard deviation is higher than He's algorithm, so the improved method is more better than He's algorithm; Observation mean value can show that two methods have declined, which demonstrates the algorithm has some defogging effects; As for information entropy, the information entropy from two methods both increase some, relatively speaking, He's is more higher, it will detail some more. Overall, compared with He's method, these objective evaluation index are considerate, the improved method can reach a defogging effect, moreover enhance defogging speed.

4 Conclusion

Based on the atmospheric imaging optical model and dark channel prior, the article puts forward a simple fast algorithm of defogging images. By firstly increasing the brightness of an image before processing, images will get brssight after defogging. And then the article estimates the value of a global atmospheric light and the initial transmission rate $t(x)$, then optimizes the $t(x)$ though morphology method, finally gets the defogging image. Experimental results show that the improved algorithm has a better robustness. And compared with He's method, this algorithm runs faster and objective assessment indicators are considerable.

Acknowledgements. This work is supported by National Natural Science Foundation of China (61072121, 60835004, 61271382), Hunan Provincial Natural Science Foundation of China (12JJ2035) and the Fundamental Research Funds for the Central Universities, Hunan university.

References

1. Guo, J., Wang, X.-T., Hu, C.-P., Xu, X.: Image dehazing method based on neighborhood similarity dark channel prior. Journal of Computer Applications 5(31), 1224–1226 (2011)
2. Yu, J., Xu, D., Liao, Q.: Image defogging: a survey. Journal of Image and Graphics 16(9), 1561–1676 (2011)
3. Tan, R.T.: Visibility in Bad Weather from a Single Image. In: Proc of IEEE Conference on Computer Vision and Pattern Recognition, pp. 1–8. IEEE Computer Society, Washington, DC (2008)
4. Fattal, R.: Single image dehazing. ACM Transactions on Graphics, 1–9 (2008)
5. He, K.-M., Sun, J., Tang, X.-O.: Single Image Haze Removal Using Dark Channel Prior. In: Proc of IEEE Conference on Vision and Pattern Recognition, pp. 1956–1963. IEEE Computer Society, Washington, DC (2009)
6. Tarel, J.P., Hautiere, N.: Fast Visibility Restoration from a Single Color Or Gray Level Image. In: Proc of IEEE International conference on Computer Vision. [S.I.], pp. 2201–2208. IEEE Press (2009)

7. Narasimhan, S.G., Nayar, S.K.: Interactive (De) Weathering of an Image Using Physical Models. In: Proceedings of the 2003 ICCV Vision Workshop on Color and Photometric Methods in Computer Vision, pp. 1387–1394. IEEE Press, Piscataway (2003)
8. Narasimhan, S.G., Nayar, S.K.: Vision and the Atmosphere. International Journal of Computer Vision 48(3), 233–254 (2002)
9. Narasimhan, S.G., Nayar, S.K.: Chromatic Framework For Visio. In: Bad Weather Proceedings of IEEE CVPR, pp. 598–605. IEEE, Washington, DC (2000)
10. Lv, X., Chen, W., Shen, I.-F.: Real-time Dehazing for Image and Video. In: 2010 18th Pacific Conference on Computer Graphics and Applications, pp. 62–69 (2010)
11. He, K., Sun, J., Tang, X.-O.: Guided Image Filtering. IEEE Transactions on Pattern Analysis and Machine Intelligence 6(35), 1397–1409 (2013)
12. Guo, F., Cai, Z.-X., Xie, B.: Video Defogging Algorithm Based on Fog Theory. Acta Electronica Sinica, 2019–2025 (2011)