

Application and implementation of dark channel prior defogging algorithm in image restoration

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Abstract. In recent years, there appeared many times of serious haze weather in a lot of places in our country. According to the data published by China Meteorological Bureau, in 2013, the average number of Chinese haze days was 2.3 days more than early years at the same period, and was the most since 1961; in 2014, the haze weather did not decrease but gradually increase. Fog is the aerosol system composed of a large number of small water droplets or ice crystals suspended in the air near the ground, and a product of condensation of water vapor coagulation in the air in the ground layer. Haze is composed of dust, nitric acid, sulfuric acid, and organic hydrocarbons in the air. Both fog and haze have a series of adverse effects, including reducing air transparency, fuzzing vision up and reducing visibility. Therefore, the haze weather causes a bad influence on people's daily life.

The formation of foggy image is affected by many factors, and the main reasons included are: particulate composition of large radius in the atmospheric medium reduces the transparency of the air, and leads to the reduced visibility of the target; at the same time, the sun light after the scattering of these particles with a large radius is enhanced. Influenced by the above two common reasons, the foggy image quality decreases to a great extent. In order to get high quality defogging image, combined with the causes of foggy image formation and its physical model, the defogging recovery processing of foggy image is conducted. Each image objective evaluation indexes of defogging images are compared and analyzed and good results are obtained.

Key words. image defogging, dark channel prior, sky region segmentation, transmittance, subjective and objective evaluation index.

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1. Introduction

The defogging processing of foggy image is a significant problem in the field of computer vision, and has a very broad application prospects. Its related research results can achieve the relevant processing of image obtained by way of aerial photography, underwater photography, and outdoor video surveillance and so on, and thus to make the processed image better used^[1-3]. In recent years, the research on image defogging method has attracted many researchers' attention, and more and more researchers are committed to image defogging method research. However, compared with other fields of image processing, image defogging research started late, and it was first proposed in 1998 by John P. Oakley that used the image enhancement method to achieve image defogging. The research history in this aspect is just over ten years, so the reference documents are limited and coupled with the complexity and randomness of weather conditions, related research on the image defogging problem is difficult^[4-5]. All kinds of defogging methods proposed by researchers at home and abroad are not particularly perfect, and are still in constant development, needing further improvement to make the image after defogging achieve better effect. With the continuous improvement of the image defogging algorithm, its scope of application will be more and more widely, and will bring more and more convenience to people's life^[6].

2. Related research based on foggy image

2.1. Concept of foggy image

In sunny weather, the formation of the image is shown in Figure 1: the object through a variety of medium particles in the atmosphere (mainly clean air) arrives at the imaging device after reflection, refraction and other physical processes, and finally obtains relatively clear images through imaging equipment. In this process, the light comes to imaging equipment has two parts: one is the light reflected by the object to the imaging equipment; the other is the light reaching the imaging device by the sun through scattering of a variety of particle in the atmosphere. The two parts of light play a role jointly to get the image of the object in the imaging device^[7-8].

In foggy weather, since a large number of suspended small water droplets or ice crystals near the ground constitute the aerosol system, coupled with the existence of suspended particles in the air, the medium components of the atmosphere change and the radius of various particles in medium components increase. Therefore, on the one hand, emergence of an aerosol system and suspended particles reduces the air transparency, deteriorates the target object's visibility deterioration, and weakens the reflection light of the target on the imaging device; on the other hand, the sun light scatters to the imaging device through various particles with an increased radius in the atmosphere is enhanced. The two parts' light changes in reaching the imaging equipment finally results in the decline of the quality of image formed in the imaging equipment^[9].

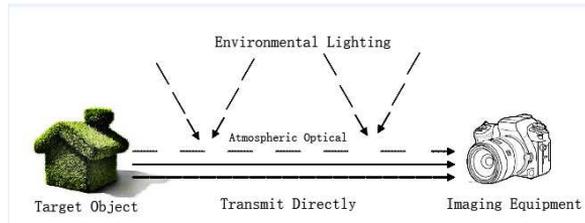


Fig. 1. Formation of images

2.2. Physical model of foggy images

The decline in the quality of images obtained in foggy weather is mainly caused by two reasons: on the one hand, because of the reduced visibility of the target, the reflection light of the object to the imaging equipment decreases; on the other hand, the degree of scattering of the environment light obtained by the sun light when passing through medium particles in the atmosphere also increases, so that the atmospheric light reaches the imaging equipment will be enhanced as well. Under the interaction of the two aspects, the foggy image physical model can be obtained under. To sum up, the foggy image physical model consists of two parts: the first part is the reflection light of the object to the image forming apparatus, namely the incident light, and this part is called as the incident light attenuation; the other part is the atmospheric light after scattering to imaging devices, which is called atmospheric light enhancement^[10].

The incident light attenuation indicates the light of the object to imaging equipment, and according to the distance between the target and the imaging equipment, the attenuation happens in exponential form, i.e.:

$$E_{Dd, \lambda} = E_0(\lambda)e^{-\beta(\lambda)d} \quad (1)$$

$E_{Dd, \lambda}$ refers to the incident light attenuation part; $E_0(\lambda)$ represents the light intensity in the target's position, namely the light intensity emitted by the target; d is the distance between the target and the imaging device, which is called the scene depth; $\beta(\lambda)$ is atmospheric scattering coefficient, which reflects the ability of the atmospheric scattering light per unit volume, and in a foggy image, it is a constant. By formula (1), it can be obtained that the incident light attenuation exponentially degenerates with the increase of scene depth.

The atmospheric light enhancement part indicates that in foggy weather, with the radius increase of various particles, the scattering of these particles as a medium on the atmospheric light will increase, and the atmospheric light coming into the imaging equipment will also increase:

$$E_{Ad, \lambda} = E_{\infty}(\lambda)e^{-\beta(\lambda)d} \quad (2)$$

The physical model of foggy images is composed of two parts: the incident light attenuation part and the atmospheric light enhancement part, so the foggy image

physical model is:

$$E(d, \lambda) = E_D(d, \lambda) + E_A(d, \lambda) \quad (3)$$

Substitute formula (1), (2) into formula (3):

$$E(d, \lambda) = E_0(\lambda)e^{-\beta(\lambda)d} + E_\infty(\lambda)e^{(1-\beta(\lambda)d)} \quad (4)$$

In addition, $I(x) = E(d, \lambda)$, $t(x) = e^{-\beta(\lambda)d}$, $L(x) = E_\infty(\lambda)$, and substitute it into formula (??) to calculate the physical model of foggy image:

$$I(x) = L(x)t(x) + A(1 - t(x)) \quad (5)$$

The foggy image model is an important foundation to achieve this paper's goal, as shown in Figure 2.

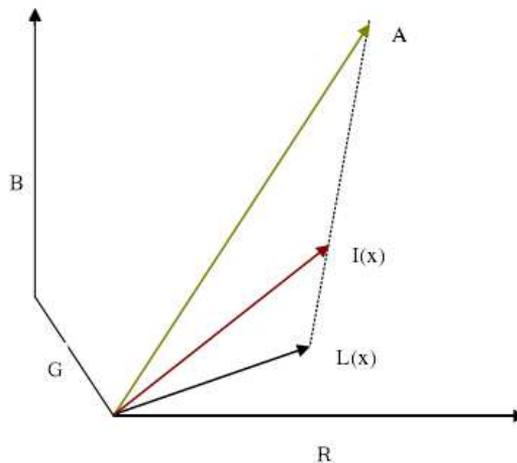


Fig. 2. Physical model of foggy image

3. Defogging algorithmic model of dark channel prior

3.1. Principle of dark channel prior

For most of the outdoor fog-free images, in each local area, there exists at least one pixel with a low intensity of color channel. Based on the observation of the database of such outdoor fog-free images, “He” comes up with an objective principle—the principle of Dark Channel Prior(DCP): In the majority of the non-sky local areas, there exist some pixels where there are at least one color channels with low intensity. That is to say, in these areas, the minimum value of light intensity is very small, which can be shown in Figure 3. The formula can be expressed as follow based on

the dark channel prior principle:

$$L^{dark}(x) = \min_{c \in (r,g,b)} (\min_{y \in \Omega(x)} (L^c(y))) \quad (5)$$

L^c means one of the three color channels of pixel L , that is R, G, B color channels; $\Omega(x)$ means a square area with X as the center and this square area is 15×15 . Based on the Dark Channel Prior principle, it is known that the value of L^{dark} is always very low and is close to 0.



Fig. 3. sunny image

According to the principle of the dark channel prior, it can be known that, in the foggy image, the existence of fog will increase the intensity value of a pixel, and which, will in turn increase the pixel whose intensity value is very low originally. That is to say, in the foggy image, the increased part of dark channel prior of a pixel equals to the fog concentration. Therefore, according to the principle of dark channel prior and the relevant information about the foggy image, the fog concentration as well as the projection information can be estimated when light passes through the fog. In this way the high-quality defogging image and the depth image can be obtained.

3.2. Defogging algorithm based on dark channel prior

There are four steps in the defogging algorithm based on dark channel prior: the estimation of transmittance, the optimization of transmittance, the estimation of atmospheric light and restoration of foggy image. The flow chart of the algorithm is shown in Figure 4.

(1) Estimation of transmittance

Estimate the transmittance based on the physical model of foggy image and the principle of dark channel prior. Presuppose that the atmosphere light is known, and the transmittance in a local area (the local area is a set square area of 15×15) is constant, then the following function can be obtained if the minimized calculation

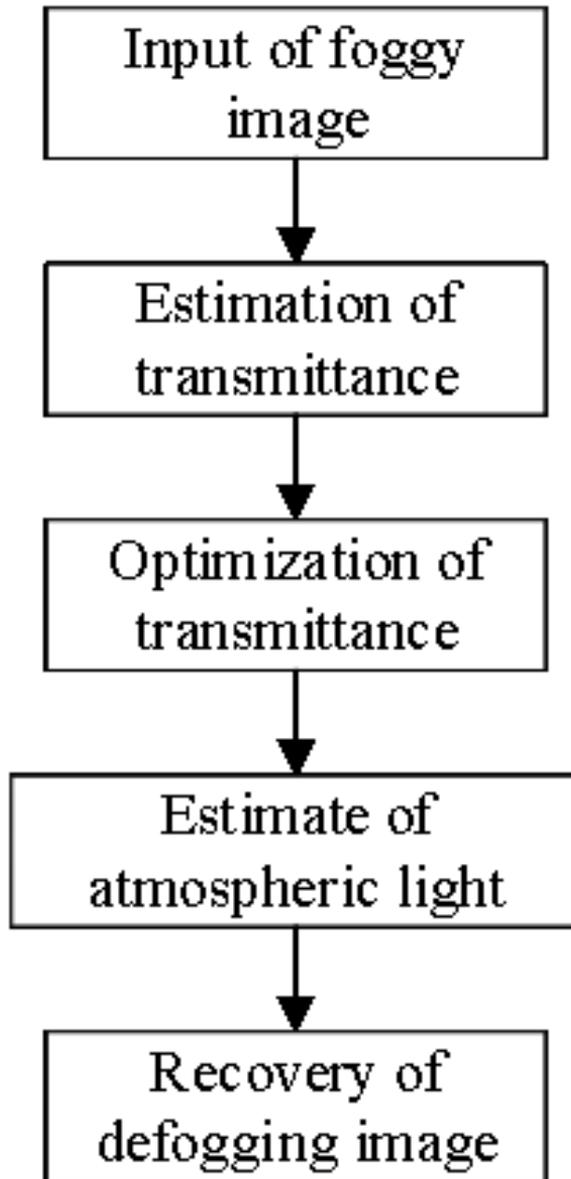


Fig. 4. Algorithm flow chart

on the physical model of foggy image is carried out (do separate calculation to the

three channel of R, G, B):

$$T(x) = \frac{1 - \min_{y \in \Omega(x)} \left(\frac{I^c(y)}{A^c} \right)}{1 - \min_{y \in \Omega(x)} \left(\frac{L^c(y)}{A^c} \right)} \quad (6)$$

(2) Optimization of transmittance

In (1), the estimated transmittance is obtained. If defogging the image and getting the final defogging image by using the estimated transmittance, then it can be found that there will be some block effect in the final defogging image. The block effect will greatly reduce the quality of the defogging image and will reduce the value of it. So the estimated transmittance can be optimized through soft matting in order to obtain a defogging image with a higher quality. Map the optimized transmittance function to $T(x)$, rewrite the $T(x)$ and $T(x)$ to T , and minimize the cost function below:

$$E(T) = T^M P T + \lambda(T - T)^M (T - T) \quad (7)$$

(3) Estimation of Atmospheric Light

From the above analysis that, the dark channel prior image of foggy images reflects the concentration of fog. Therefore, the atmospheric light can be selected according to the dark channel prior image of foggy images. First, select the brightest 0.1% pixel in the dark channel prior image. Then, map the locations of these pixels to the corresponding locations of the input image. Finally, select the biggest pixel value in the corresponding input image as the atmospheric light. In this way, since the atmospheric light obtained is not necessarily the brightest position in the whole image, the selected atmospheric light has a higher accuracy. However, when there exist a large area of white non-sky area, such as the white building, white tent, there will be much more mistakes in the selected atmospheric light, which is one of the problems to be solved in this passage.

(4) Restoration of foggy image

After the optimized projection rate and atmospheric light are obtained, the final defogging image $L(x)$ can be got according to the physical model of foggy images:

$$L(x) = \frac{I(x) - A}{\max(T(x), T_0)} + A \quad (9)$$

In this equation, T_0 is the lower limit of $T(x)$ and its set to 0.1. When $T(x)$ is close to 0, then $L(x)T(x)$ will also be close to 0; therefore, the defogging image obtained is more likely to contain noise. In order to avoid this situation, which will affect the quality of the acquired defogging image, we set T_0 to acquire defogging image with a higher quality.

4. Application and implementation of dark channel prior defogging algorithm in image restoration

Fog-free images are obtained from fogging image based on dark channel prior principle and optimized defogging algorithm. But when it comes to the quality of

the defogging image, it is necessary to take up a quality evaluation. In the existing methods, there is no systemic method for the quality evaluation of defogging image. According to the characteristics of the defogging image, in this thesis, the quality evaluation method is used that combines the subjective evaluation indicators and objective indicators to get the quality evaluation of defogging image which is obtained based on the dark channel prior principle and optimized defogging algorithm. In addition, the final value of defogging optimization algorithm that based on dark channel prior theory lies in its application. The defogging algorithm is applied to many fields in our daily life, such as the outdoor monitoring system, satellite remote sensing monitoring system and so on. In addition, defogging is also needed in the recognition of license plate image in foggy weather and thus the value of the algorithm that is based on dark channel prior principle and optimized defogging algorithm is realized in this process.

4.1. Evaluation index of defogging image

Most of the time, the subjective evaluation index is to select a certain number of observers randomly, and theoretically, the more the observer is, the better the result is. After each observer makes an evaluation to the defogging image respectively according to their personal visual effect, the evaluation grades or evaluation scores can be obtained. And finally the final evaluation index can be got after averaging all the the evaluation grade or evaluation score given by all observers. Subjective evaluation index depends on the observer's personal experience, visual perception and so on. Due to the influence of the environment, personal experience, personal emotion and other factors, there may be a large errors between the subjective evaluation index obtained by the observers and the actual situation.

The seven existing objective evaluation indexes of image quality include mean square error, signal to noise ratio, information entropy and average gradient, visible edge ratio, the percentage of saturated black or white pixels, and the structural similarity.

4.2. Experimental results and analysis of defogging image

There are three methods to determine the quality of defogging optimization algorithm based on dark channel prior theory:

Fog removing experiment of real foggy image with the same atmospheric light but different transmittance

By comparing the subjective and objective evaluation indexes of the proposed defogging algorithm based on the dark channel prior principle and other algorithms, the quality of the algorithm can be judged.

First, set the atmospheric light values in each algorithm to the atmospheric light values in the "He" algorithm (the atmospheric light value of the image in Figure 5 is 0.86667), and then compare the results of each algorithm, which can be shown in figure 5.

It can be seen from Figure 4 (b) that, the sky region (the red region in (b))



Fig. 5. image fusion method

obtained by the “He” algorithm is smaller, and does not contain most of the sky regions in the image. Therefore, the atmospheric light value obtained will have a certain deviation. Subjectively, if the gray image that is disposed by median filtering is used as optimization of transmittance, the defogging image (e) obtained is deeper in color, but the contrast ratio is larger in the foregrounding of the image and the scene content is clear with more practical value; if the gray reverse image that is disposed by median filtering is used as optimization of transmittance, the prospect part of the defogging image (f) obtained is more likely to be in line with the actual situation. The greater the distance, the obscurer the content of the scene and the color tends to be white; if the image is fused with optimization transmittance and the fused image is taken as optimization transmittance, defogging image like (g) can be obtained, which combines the advantage of (e) and (f), and thus defogging image with a higher quality can be acquired.

5. Conclusion

With the rapid development of science and technology, people’s life becomes more and more convenient. But at the same time, there are also a series of problems that affect people’s lives and bring people a lot of inconvenience, and haze is one of these problems mention above. It is necessary for us to reduce and tackle the haze problem. Since it takes time to solve the problem, it is therefore requisite for people to reduce its distress on life before that. The presence of haze brings those problems to the image acquired through various ways as a decrease in contrast, color, clarity and other issues, which will reduce the value of images, and is likely to cause unnecessary losses. In order to solve these problems, it is necessary to defog the foggy image obtained. The analysis in this paper of defogging algorithm based on the dark channel prior principle plays a great role in the research of image

restoration.

References

- [1] W. WANG, X. YUAN: *Recent advances in image dehazing*. IEEE/CAA Journal of Automatica Sinica 4 (2017), No. 3, 410–436.
- [2] S. SANTRA, B. CHANDA: *Day/night unconstrained image dehazing*. International Conference on Pattern Recognition (2017), 1406–1411.
- [3] A. GALDRAN, J. VAZQUEZ-CORRAL, D. PARDO D: *Fusion-Based Variational Image Dehazing*. Signal Processing Letters 24 (2017), No. 2, 151–155.
- [4] Z. LUAN, Y. SHANG, X. ZHOU: *Fast Single Image Dehazing Based on A Regression Model*. Neurocomputing 245 (2017), 10–22.
- [5] J. E. KHOURY, S. L. MOAN S, J. B. THOMA: *Color and sharpness assessment of single image dehazing*. Multimedia Tools & Applications 8 (2017), 1–22.
- [6] J. PAN, D. SUN, H. PFISTER: *Deblurring Images via Dark Channel Prior*. IEEE Trans Pattern Anal Mach Intell 99 (2017), 1–1.
- [7] J. S. XIAO, W. GAO, B. Y. ZOU: *Image Dehazing Based on Sky-Constrained Dark Channel Prior*. Acta Electronica Sinica 45 (2017), No. 2, 346–352.
- [8] T. ZHANG, L. LI, R. MO: *An improved estimation transmission method for Dark Channel Prior*. Proceedings of the Spie (2017).
- [9] B. POCHON, A. BALLEY, H. SEYDOUX: *DRONE WITH A FRONT-VIEW CAMERA WITH SEGMENTATION OF THE SKY IMAGE FOR AUTO-EXPOSURE CONTROL*. US20170078552 (2017).
- [10] Q. LEI, C. SHI, T. CHEN: *Single Sea Image Haze Removal Method Based on Segmentation of Sky Area*. Computer Engineering (2017).

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