A defogging method based on weigh least square filtering

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Abstract: Image captured in foggy weather conditions often suffer from bad visibility, it is critical to restore and preserve edge detail in image defogging. In this paper, we propose a fog-free method from a single image based on weigh least square filtering which can preserve edge details well and smooth texture. First, the atmospheric veil is estimated by making use of the weigh least square filtering, so that we can obtain the atmospheric transmittance distribution. Then, estimating the atmospheric light by dark channel prior theory. Finally, the fog-free image is recovered by transforming the atmospheric scattering model. The experimental results show that the algorithm has a small time complexity, and effectively restore the fog image, which is beneficial to the realization of real-time defogging.

Keywords: Defogging; Weigh least square filtering; Atmospheric veil; Atmospheric scattering model

1 Introduction

When one takes a picture in foggy weather conditions, the obtained images would get serious degradation problems in the color and contrast fidelity due to the influence of atmospheric scattering which aroused by particles in air likes dusts and drops. As many people know, it would difficult to extract image features from a degraded image, eventually causes some monitoring systems based on feature details ineffective, such as Outdoor monitoring system, Traffic navigation system and Satellite remote sensing system.

With the development and wide application of computer vision, image defogging has attracted more and more attention of many researchers. Now, the image defogging methods are mainly divided into two categories. The first is based on image enhancement, which ignores the mechanism of atmospheric scattering, just to improve the visual effect by image enhancement, it is easy to lose the image details[1]. The second is based on image restoration, which obtained the restored image by transforming the atmospheric scattering model and plenty of image defogging algorithms have put forward based on this. Representative works include [2][3][4][5][7]. Fattal [3] proposed a refined image formation model to account for the surface shading and the scene transmission. Under the assumption that the two functions are locally statistically uncorrelated, a fog image can be broken into regions of constant albedo, from which the scene transmission can be inferred. Tan [2] proposed to enhance the visibility of a fog image by maximizing its local contrast. His method can generate quite compelling results, especially in regions with very dense fog. However, the restored image often suffers from distorted colors and significant halos. He [4] proposes a dark channel prior theory, according in his theory, atmospheric transmittance distribution can be accurately acquired, but in He’s paper, it takes long to refined the atmospheric transmittance distribution. Tarel [5] proposed a simply method which estimates atmospheric veil by median filtering, but the median filtering is not a good edge-preserving filter, so it would arouse halos under the inappropriate parameters.
In view of the above problems, this paper proposes a single image defogging algorithm based on weigh least square (WLS) filtering [6]. First, estimating the atmospheric veil by taking full use of the properties that WLS filtering is available to preserve edges and smooth texture. Then, using the dark channel prior theory to estimate the A. Finally, the restored image is recovered by transforming the atmosphere scattering model.

2 Atmosphere scattering model

In field of image restoration, the following mathematical model proposed by McCartney [14] in 1975 is widely used to describe the imaging process of fogging image:

\[ I(x) = J(x)t(x) + A(1 - t(x)) \]  

(1)

\[ t(x) = \exp(-\beta d(x)) \]  

(2)

Where \( I \) is the fogging image acquired by visual system; \( J \) is the defogging image or light intensity reflected at the surface of the scene; \( x \) is used to mark the location of the pixels in image; \( A \) is the atmospheric light assumed as a global constant; \( t \) denotes the transmission map of the image, which reflect the depth information of the scene and it can be expressed by (2); \( \beta \) is scattering coefficient of the atmosphere and \( d \) represents the distance between the target scene and the observer.

According to the atmospheric scattering model, the images obtained by the imaging device are mainly affected by the transmittance and atmospheric light in foggy weather. In the equation, the first term directly decays the reflected light in the scene, and with the deepening of the depth of the scene, the degree of attenuation increases at the exponential level, and the second term in the formula indicates that the ambient light is involved in the imaging process, which leads to the degradation of the quality of the obtained image. The final result is that with the increase of scene depth, the degradation of image quality becomes more and more serious. In extreme cases, when the atmospheric transmittance is zero, the imaging process would only determined by the atmospheric light, and the details of the image would lost.

The purpose of fog removal based on atmospheric scattering model is to restore the clear image \( J \) from the foggy image \( I \), because the mathematical expression of the atmospheric scattering model is underdetermined, \( I \) is the only known variable, \( J, t \) and \( A \) are unknown. To restore \( J \), we must estimate \( A, t \). Because the value of \( t \) is related to the atmospheric scattering coefficient and the depth of the scene, it is impossible to estimate the data directly. So the atmospheric veil \( V \) is introduced as follows:

\[ V(x) = A(1 - t(x)) \]  

(3)

3 Imaging defogging algorithm based on WLS filtering

In this section, we introduce the WLS filter and apply it into image defogging, compared with the other edge-reserving filters, the WLS filter is more efficient [6].

3.1 WLS filtering

Smoothing an image can serve many purposes, one of them is to remove its confounding details, while the goal of bringing out its main features. To do so, many nonlinear filters were
designed by researchers, such as the median filter, bilateral filter[16] and the anisotropic-diffusion filter. All of those filters can preserve edges while still smoothing out uninformative details, but there is a problem of those filters that they can not run efficiently. In order to solve the above problem, Z. Farbman[6] proposed a new filter called WLS. The mathematical expression is as follows:

$$\sum_p \left( u_p - g_p \right)^2 + \lambda \left( a_{x,p}(g) \left( \frac{\partial u}{\partial x} \right)_p + a_{y,p}(g) \left( \frac{\partial u}{\partial y} \right)_p \right)^2$$

(4)

where $u$ represents the filtered image, $g$ is the input image, $p$ denotes the position of pixels, $a_{x,p}$ and $a_{y,p}$ is the smooth weight. $\lambda$ is the balance parameter.

Using matrix calculation, the above formula can be rewritten as follows:

$$(u - g)^T (u - g) + \lambda \left( u^T D_x^T A_x D_x u + u^T D_y^T A_y D_y u \right)$$

(5)

Where $A_x$ and $A_y$ is the diagonal matrices of $a_{x,p}, a_{y,p}, D_x$ and $D_y$ are the forward and backward difference matrices. When the above formula obtains the minimum value, $u$ satisfies the following:

$$(I + \lambda L_g) u = g$$

(6)

$$L_g = D_x^T A_x D_x + D_y^T A_y D_y$$

$$a_{x,p}(g) = \left( \frac{\partial \ell}{\partial x}(p) \right)^u + \varepsilon, a_{y,p}(g) = \left( \frac{\partial \ell}{\partial y}(p) \right)^u + \varepsilon$$

(7)

Where $\ell$ is the logarithm of the bright channel of the input image $g$, $a$ is an amplification factor, and the value range is [1.2, 2]. $\varepsilon$ is a gain term to prevent this occurrence of 0 and is typically set to 0.0001.

Eventually, we can obtained the filtered image from formula (6):

$$u = (I + \lambda L_g)^{-1} g$$

(8)

3.2 Estimating the atmospheric veil

According to the physical model represented by formula (3), the atmospheric veil $V$ is constrained by two conditions: 1) $V(x) \geq 0.2$; 2) $V(x) \leq I(x)$, $V$ is not greater than the minimum color component of $I$. In this paper, assuming that the restored contrast is improved as much as possible, and the depth of field changes slowly at the non-edge[12]. The atmospheric veil is estimated by two steps from thick to fine. The first step, use the minimum color component of $I$ as rough atmospheric veil:

$$V^c(x) = \min_{c \in \{R,G,B\}} \left( I^c(x) \right)$$

(9)

Because the atmospheric veil is only related to depth of field, there are no relations with albedo[7]. So in the second step, the rough estimation of atmospheric veil should be smoothed to maintain the edge details of the sudden change of depth of field, which can be regarded as a filtering problem. In order to achieve this goal, WLS filter can be adopted to smooth the atmospheric veil:

$$V(x) = \text{WLS} \left( V^c(x) \right)$$

(10)
3.3 Restoring foggy image

After obtaining the atmospheric veil $V$, the transmission $t$ can be solved by transforming the formula (3). However, in the actual image acquisition process, it is difficult to completely purify the air and does not contain any impurity molecules, so when looking at a distant object, it is always blurred. Therefore, in order to make the restored image closer to the actual situation, a constant $w$ can be introduced as adjustment factor to control the degree of defogging, which is greater than 0, less than or equal to 1. Eventually, the expression of the transmittance can be expressed as follows:

$$ t(x) = 1 - w \frac{V(x)}{A} $$

But there is still a unknown parameter $A$ in formula (10). $A$ is an important parameter in the process of image defogging. It is significant to accurately estimate the atmosphere light $A$, so in this paper, we used the dark channel prior theory to estimate the $A$: First, selecting the top 0.1% pixels with the highest brightness in the dark channel, the pixel values of the fogged images corresponding to those pixels are averaged, and the average value is used as an estimate of the atmospheric light $A$.

Finally, the parameters of $t$ and $A$ are solved, restored image $J$ can be easily expressed as follows:

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

where $t_0$ is a lower limit value to prevent the occurrence that the denominator is zero.

4 Experiments and discussions

In this section, we will compare our algorithm with bilateral filtering algorithm in two ways: subjective visual evaluation and run times.
From the two images in Figure 2, it can be seen that the results of bilateral filtering algorithm and this paper algorithm are similar, the defogging effect is equivalent. But from the table 1, it is obvious that this paper algorithm is more efficient than bilateral algorithm, so this paper algorithm is good for application to real-time defogging systems.

Table 1 Comparison with different fog dehazing algorithm’s run times

<table>
<thead>
<tr>
<th>Image size/pixel</th>
<th>Bilateral filter algorithm/s</th>
<th>This paper algorithm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>440*440</td>
<td>2.492</td>
<td>0.611</td>
</tr>
<tr>
<td>600*400</td>
<td>3.153</td>
<td>0.8416</td>
</tr>
</tbody>
</table>

5 Conclusion

In this paper, a new defogging algorithm based on weigh least square filtering is presented. First, estimating the atmospheric veil by WLS filtering, then, using the dark channel prior theory to estimate the A. Finally, the restored image is recovered by transforming the atmosphere scattering model. Compared with classical defogging method based on bilateral filtering, this paper algorithm is better in time performance, because WLS filtering’s time complexity is very low.

Reference:

prior[C]/Proceedings of IEEE Conference on Computer Vision and Pattern Recognition


