Adaptive Demisting Algorithm Based on Polari metric Image

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Abstract. Aiming at the problem of high complexity and poor robustness of the defogging algorithm of the existing polarized image, an adaptive de-fogging algorithm based on the polarized image is proposed. Based on the principle of image dark channel, the algorithm selects minimum mean square filter to automatically extract the sky region, and obtains the radiation intensity information after scene restoration. Experimental results show that the proposed algorithm can effectively improve the sharpness of the polarized image and increase the robustness of the algorithm.

1. Introduction
In the foggy day, the images obtained due to atmospheric absorption and scattering of light seriously degrade, posing great difficulties for transportation, video surveillance and even military reconnaissance. Therefore, it is of great practical significance to reconstruct and enhance the details of the scene from the foggy images. Existing image de-fogging techniques can be roughly divided into two categories: one is based on the physical model of atmospheric scattering and the other is based on image enhancement. Among them, the methods based on the atmospheric scattering physics model can achieve the ideal de-fogging effect, and thus become the focus of image de-fog technology, but such methods usually need to know the depth information of the scene. In the de-fog method proposed in [1], the depth information of the scene is obtained by radar. Reference [2] calculates the depth ratio of each point of the scene with reference images of the sunny and foggy scenes. Both methods need to involve multiple scene images obtained under different weather conditions, so the timeliness is poor. Document [3] proposed a way to achieve defog using a single image, but requires manually setting vanishing points and specifying the depth of field. Literature [4] proposed to achieve the purpose of de-fog by expanding the local contrast of reconstructed images. Literature [5] adopted blind source separation to extract scene depth information; and [6] proposed de-fogging based on dark primary colors. The above three methods can achieve a single image to automatically fog, but all involve complex solution operation, so timeliness is poor. Literature [7] obtained the depth information of the scene according to the polarization characteristics of the atmosphere and finally restored the degraded image. The algorithm has low computational complexity and real-time de-fogging capability. However, the gray value of a single pixel is used to select the region in the image to estimate the relevant parameters, Prone to error, poor robustness of the algorithm.

In view of the deficiencies of defogging method proposed in [7], this paper presents an adaptive polarization image defogging method.
2. **Defoaming algorithm based on polarization image theory**

According to the atmospheric scattering model [8], the decay model and the atmospheric light model, which play a dominant role in the foggy day, are the dominant ones.

\[
I(\beta, d) = D(\beta, d) + A(\beta, d)
\]  

(1)

In the formula, \(I(\beta, d)\) is the image intensity information obtained by the imaging system; \(D\) represents the intensity of the scene received at the observation point; \(A\) indicates the atmospheric light intensity received at the observation point; \(\beta\) represents the atmospheric scattering coefficient; \(d\) is the distance from the scene to the observation point.

The attenuation model describes the attenuation of light waves from scene to observation point. \(L^{\text{object}}\) Represents the radiation intensity of the scene.

\[
D(\beta, d) = L^{\text{object}} e^{-\beta d}
\]  

(2)

The atmospheric light model describes the effect of light scattering on the received light at the observation point. \(A\) represents the atmospheric light intensity at infinity.

\[
A(\beta, d) = A_{\infty} (1 - e^{-\beta d})
\]  

(3)

According to the optical principle, the vibration of the light wave will be changed after reflected by the surface of the object. For linear polarization imaging system:

\[
I(\beta, d) = I_{H}(\beta, d) + I_{V}(\beta, d)
\]  

(4)

In the formula, \(I_{H}(\beta, d)\) represents the intensity of linearly polarized light parallel to the incident surface, \(I_{V}(\beta, d)\) represents the intensity of linearly polarized light perpendicular to the incident surface.

It can be seen from the above equation (2) (3) that the light intensity of the scene decays exponentially with distance while the atmospheric light intensity \(A\) increases exponentially with distance. Therefore, the polarization of the light wave reaching the linearly polarized imaging system is mainly caused by atmospheric light [8]. so that the following formula holds:

\[
\begin{align*}
I_{H}(\beta, d) & \approx 0.5D(\beta, d) + A_{H}(\beta, d) \\
I_{V}(\beta, d) & \approx 0.5D(\beta, d) + A_{V}(\beta, d)
\end{align*}
\]  

(5)

According to the definition of degree of polarization, the following formula holds:

\[
\begin{align*}
P_{x}(\beta, d) & = \frac{A_{H}(\beta, d) - A_{V}(\beta, d)}{A(\beta, d)} \\
P_{y}(\beta, d) & = \frac{I_{H}(\beta, d) - I_{V}(\beta, d)}{I(\beta, d)}
\end{align*}
\]  

(6)

\(P_{x}(\beta, d)\) Is a global constant, Therefore, once you know \(A_{\infty}\) and \(P_{x}\), you can restore the radiation intensity of the scene.
3. Adaptive demisting algorithm based on polarization image

It can be seen from the above process that the defogging method proposed in [7] has the following deficiencies:

(1) The parameters in the image are selected by the gray value of a single pixel to estimate the relevant parameters, which is prone to error and the robustness of the algorithm is poor.

(2) The algorithm considers that the polarization of the light reaching the imaging system is mainly caused by the atmospheric light, and the polarization state of the light reflected by the scene is negligible. This assumption is valid for the scenes with higher polarizations in the vicinity will cause greater deviation.

In view of the above insufficiency, this article has improved this algorithm, the algorithm is described as follows:

3.1. Polarization information analysis

Assuming that the fog is evenly distributed, the fogiest area should be the sky area at infinity on the image. According to the dark color priors proposed in Ref. [6], most local outdoor fog-free images have pixels with low intensity values in at least one color channel in each of the local areas, but after fog interference, the brightness itself is greater, so the dark primary colors of the image areas covered by dense fog have higher intensity values. Therefore, by using the priori of dark primary colors, the concentration of fog can be estimated directly and the sky region corresponding to the maximum fog concentration can be found, so that the atmospheric light information can be obtained automatically.

The polarization of the light wave can be characterized by the Stokes parameter $[I \; Q \; U \; V]^T$, The $V$ component is generally negligible. $\theta$ Represents the polarization angle (the value is $0^\circ$, $60^\circ$ or $120^\circ$), then the transmitted light intensity in the polarization direction $\theta$ is:

$$I_\theta = 0.5(I + Q\cos(2\theta) + U\sin(2\theta)) \tag{7}$$

As long as three polarizations of the image $I_\theta(\beta,d)$ are obtained, the images $I(\beta,d)$, $Q(\beta,d)$ and $U(\beta,d)$ can be obtained by simultaneous equations, whereby the polarizability image formula can be obtained:

$$P(\beta,d) = \sqrt{Q(\beta,d)^2 + U(\beta,d)^2} / I(\beta,d) \tag{8}$$

3.2. Getting the atmosphere light information

According to Eq. (7), the dark channel that defines the polarization image is:

$$I_{dark}^\theta(\beta,d) = \min_{\theta_1 \in \{\theta_1, \theta_2, \theta_3\}} \left( \var(I_\theta(s,t)) \right) \tag{9}$$

In the formula, $W(\beta,d)$ is a local area centered at pixel $(\beta,d)$. Use the dark channel can find the corresponding local area of the polarized image corresponding to the maximum brightness:

$$\Omega = \{ (\beta,d) | I_{dark}^\theta(\beta,d) \geq T \} \tag{10}$$

$T$ is the brightness threshold. Which can be estimated atmospheric light intensity $A_\infty$ and degree of polarization $P_\lambda$ were:
In the formula, \( \text{card}(\Omega) \) represents the base of set \( \Omega \).

Find the sky regions in images \( I(\beta,d) \) and \( P(\beta,d) \) from Eqs. (9) And (10), and then estimate the atmospheric light intensity \( A_\infty \) and the degree of polarization \( P_d \) according to Eq. (11).

### 3.3. Scenery radiation intensity estimation

According to the formulas (1) - (6), deducting the influence of \( A \) and compensating the attenuation of \( D \), the estimated radiation intensity of the scene can be obtained by inversion:

\[
L_{\text{object}}(\beta,d) \approx A_\infty \frac{P_d(\beta,d)I(\beta,d) - P_i(\beta,d)I(\beta,d)}{P_i(\beta,d)A_\infty - P_i(\beta,d)I(\beta,d)}
\]

(12)

Then by the type (12) to restore the scene to obtain radiation intensity images.

### 4. Experiments and results analysis

In order to verify the feasibility and effectiveness of the proposed method, the linear polarization imaging system independently developed by the project team is used. The polarization imaging system transmits through a band of 665 nm with a bandwidth of about 50 nm using a 4-channel CCD imaging system. The front of the CCD is equipped with a linear polarizer. The angle between the transmitted axis and the selected reference direction is 0°, 60° and 120°, respectively. The last one is the intensity camera without a linear polarizer (normal camera). The internal light path structure shown in Figure 1.

![Polarization imaging device](image)

**Figure 1.** Polarization imaging device

Under foggy conditions with visibility less than 1Km, the polarization image test of multiple sets of scenes was performed on a building 600m from the camera. Polarized image obtained resolution of 1392 × 1040 pixels, quantified into 8-bit grayscale image.
In the middle process of calculating the polarization image information by the Stokes formula, four images as shown in Fig.2 appear, and the gray image of the intensity image shown in Fig.1 (all images are grayscale images for more direct comparison of the image information) The information represented by the latter three images respectively corresponds to I (total light intensity), Q (linearly polarized light intensity in the horizontal direction) and U (linearly polarized light intensity in the direction of 45° / 135°).

Polarization information is analysed by the four graphs in Fig.2, and the obtained result is shown in Fig.3. Fig.3 (a) shows the grayscale image of the intensity image, and Fig.2 (b) shows the polarization image directly synthesized by the formula. As can be seen from Fig.3 (b), the gray values of some pixels in the near scene are relatively bright, indicating the high degree of polarization. Therefore, the influence on the subsequent processing must be considered.
Figure 4. Linear polarization image (a) [7] extracted the sky region (b) The paper extracted the sky region (c)

The 4 $\times$ 4 window was used to obtain the composite linear polarization image. The result is shown in Fig.4 (a). The gray value characterizes the polarization of the object. In the past image de-fog method, the pixel region with the largest gray value in the image is usually regarded as the sky region [9]. However, in the actual image, the brightest pixel may be the object with higher reflectivity, Such as the outline or distant buildings of the nearby building in Fig.2 (a). The average brightness of pixels with the brightness of 0.5 % is selected as the segmentation threshold, and the algorithm proposed in [7] is simulated. The default selected region is as shown in Fig.4 (b), the selected region is more and irregular, The algorithm uses the same threshold, the minimum mean square automatically extract the image of the sky region, the results shown in Fig.4 (c) below. As can be seen from Fig.4 (c), the method of acquiring the sky region using the least mean square dark channel image is more accurate and robust.

Figure 5. Before and after the restoration of polarized images and histograms

Fig. 5(b) is the final de-fog recovery result obtained by this method. It is not difficult to find by comparing with the synthesized polarization image that the reconstructed image has obvious improvement in sharpness. Fig. 5 (c) and (d) show the histogram of the gray level of the composite polarization image and the restored polarization image respectively. From the figure it can be seen that the gray level distribution of the restored image is more extensive and balanced.
In order to quantitatively describe the image quality before and after restoration, three quantitative evaluation indexes, image entropy $E_n$, gray variance $G_d$ and average gradient $A_s$, were used for quantitative analysis [7].

Among them, the image entropy is an important index to measure the richness of the image information; the gray variance reflects the degree of deviation of the gray value of each pixel in the image from the average value of the image; the average gradient reflects the small detail features in the image, Sharpness.

Here we compare the global histogram equalization processing, the polarization de-fogging method proposed in [6], the de-fogging method proposed in [7] and the adaptive de-fogging method presented in this paper. The calculation results are shown in Table 1. It can be seen that compared with the above four methods, the resulting image obtained by the repair method proposed in this paper has the largest image entropy and average gradient. The de-fogging method proposed in [7] which is superior to the method proposed in [6], but the former is inferior to the latter in terms of average gradient. The larger the image entropy, the more abundant the image information. The larger the gray variance is, the wider the gray distribution of the image pixels. The larger the average gradient is, the better the image resolution is.

| Method                  | Image entropy | Gray variance | Average gradient |
|-------------------------|---------------|--------------|-----------------|
| Original image          | 3.672         | 5548         | 121.2           |
| Histogram equalization  | 3.648         | 6769         | 122.3           |
| Literature [6]          | 4.085         | 5621         | 125.0           |
| Literature [7]          | 4.111         | 5889         | 123.4           |
| This paper              | 4.212         | 5786         | 126.8           |

In terms of algorithm time complexity, the rest of the three methods are compared here. Assuming that the size of the image is $M \times N$ and the window size is $W \times H$, the time complexity of the global histogram equalization process is $O(M \times N)$. The method proposed by [7] is $O(MN \times MN + M \times N \times W \times H)$, the time complexity of the proposed defogging algorithm is $O(M \times N \times W \times H)$. Since $\min(M, N) >> \max(W, H)$ usually exists, the proposed method is superior to the one proposed in [7] in terms of computational complexity.

5. Conclusion
Due to the scattering effect of the atmosphere, the image of foggy weather has the characteristics of low contrast and unclear scene, which brings many inconveniences to the application. Therefore, it is of great significance to reconstruct the image of foggy weather and realize the clear imaging. In order to solve the problem of defogging algorithm based on polarization imaging, this paper uses the dark channel of polarization image to realize the robust automatic extraction of atmospheric light information. Aiming at the anomalies that occur when the atmospheric light intensity distributions are inverted due to the high degree of polarization of the target in the image, a simple and effective method is proposed. Experimental results show that the proposed adaptive de-fogging algorithm can get better recovery results.

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