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Image dehazing technique based on polarimetric spectral analysis

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ABSTRACT

Image took under hazy weather suffers from poor contrast and resolution, the haze particles will attenuate the light reflected by the targets and add unwanted scattering light. Based on the fact that the target reflection and scattering light have different polarimetric characteristics, light's power to penetrate the haze particles is linked with wavelength, this paper combines the polarimetric dehazing technique with spectral analysis, firstly proposed the polarimetric spectral dehazing method. A polarimetric spectral imager is used to obtain data under a continuously changing weather circle, the dehazing result is analyzed under five different spectral channels of 451.4 nm, 551.2 nm, 650.9 nm, 750.7 nm and 850.5 nm. The results show that our method can effectively recover the haze degenerated image under visible and infrared channels, the restoration quality of detailed information of the near-field and the far-field targets are in varying degrees under different channels. The dehazing process can enhance the image contrast by 1.68–3.64 times under different wavelengths. Two correction factors, which regularity is given for particle use, are introduced to revise an image restoration result.

1. Introduction

The worsening air pollution is causing serious haze problems in China [1,2], the air quality of nearly half of the days in 2015 in big Chinese cities like Beijing and Shanghai had failed to reach the standard. The high concentration of aerosol [3,4], which can attenuate the object radiance and add unwanted scattering light into the total intensity, has a serious effect on the resolution and contrast of the imaging quality. Ordinary imaging techniques can not function properly under hazy weather which can cause serious problem for information extraction and processing.

The image-dehazing techniques can be roughly categorized into two kinds: the method based on image enhancement, such as linear transformation [5], structure preserving [6] and dark channel prior [7], the method based on physical model, such as polarimetric image-dehazing [8,9]. The image enhancement methods, which focus on the haze-degraded image itself without considering the physical process of image degeneration, use computer vision techniques to enhance the image contrast, the loss of some detailed information is inevitable. The airlight scattered from the haze particles is partially polarized, meanwhile, the direct light reflected from the scene can be approximately considered as non-polarized light. The

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polarimetric image-dehazing technique, which utilizes the polarimetric differences between the airlight and the direct light to extract the object radiance from the total intensity, can restore the detailed information of the image.

The research on polarimetric dehazing has mainly been focused on single-band's visible image at present, based on our previous work [10,11], the image dehazing technique based on polarimetric spectral analyses, which has not been reported [9,12,13], is introduced. The object radiance's ability to penetrate the haze particles has a huge difference under different spectral channels, it is of practical significance to combine the polarimetric dehazing method with spectral analysis. The polarimetric spectral imager used in this paper can obtain the two-dimensional spatial information, one-dimensional spectral information and polarimetric information simultaneously. This image restoration method utilizes the Stokes parameters and the Mueller matrix to extract polarimetric information from the scene and obtains the image restoration result through the correction of a series of bias factors. The image characteristic and the dehazing process of near-field and far-field scenes under different spectral channels are analyzed. This method realized multi-spectral image restoration based on polarimetric dehazing which makes it possible for the imaging spectrometer to work under hazy weather.

2. Atmospheric scattering model and polarimetric dehazing method

The total intensity of the light I received by the imager under hazy weather can be divided into two parts: the part generated by the reflection of targets which is the direct light reflected from the scene D, the part generated by the scattering of the atmosphere which is the airlight scattered from haze particles A. Under hazy weather, the scattering of aerosol will add unwanted airlight into the total intensity of light and the absorption of aerosol will attenuate the reflection of the scene. The energy imager receives will be the object radiance L when there is no aerosol between the imager and the scene. The direct light reflected from the scene D is non-polarized light which decreases with the observation distance, meanwhile, the airlight scattered from the haze particles A is partial polarized which increases with the observation distance. Based on the difference of D and A, the image restoration can be realized by separating the airlight from the total intensity and compensating the attenuation of the direct light. In Schechner's theory [14], the object radiance L after the image restoration is

$$L = \frac{I^{\perp} + I^{\mathrm{II}} - \left(I^{\perp} - I^{\mathrm{II}}\right)/p}{1 - \left(I^{\perp} - I^{\mathrm{II}}\right)/pA_{\infty}} \tag{1}$$

where $I^{\perp}$ is the image taken when the orientation of the polarizer is perpendicular to the plane of incidence, I^{II} is the image taken when the orientation of the polarizer is parallel with the plane of incidence, A_{∞} is the airlight from an object at an infinite distance(such as the sky region), p is the degree of polarization. The total intensity of the light received by the polarimetric imager under hazy weather changes with the orientation angle of the polarizer α, when the orientation of the polarizer is parallel with the plane of incidence ($\alpha = \theta^{\mathrm{II}}$), the intensity of the airlight scattered from haze particles A^{II} is the smallest which represents the best state of the original image, when the orientation of the polarizer is perpendicular to the plane of incidence ($\alpha = \theta^{\perp}$), the intensity of the airlight scattered from haze particles $A^{\perp}$ is the largest which represents the worst state of the original image.

Based on the Stokes parameters and the Mueller matrix, the dehazing algorithm extract the polarimetric information through four linear polarimetric images with fixed orientation of 0°, 45°, 90° and 135° which means no manual operation or subjective evaluation is needed during the hole image restoration process. The Stokes parameters are

$$\begin{cases} S_0 = I(0) + I(90) \\ S_1 = I(0) - I(90) \\ S_2 = I(45) - I(135) \end{cases} \tag{2}$$

where S_0 represents the total intensity of the image, S_1 and S_2 represent the linear polarimetric characteristic of the image. The angle of polarization perpendicular to the plane of incidence is $\theta^{\perp} = \frac{1}{2}\arctan\frac{S_2}{S_1}$, the angle of polarization parallel with the plane of incidence is $\theta^{\mathrm{II}} = \theta^{\perp} + \frac{\pi}{2}$. Base on the Mueller matrix, the total intensity of the image on the angle of polarization α is

$$I(\alpha) = \frac{1}{2}(S_0 + S_1\cos 2\alpha + S_2\cos 2\alpha) \tag{3}$$

The algorithm acquires $I^{\perp}$ and I^{II} by substituting $\theta^{\perp}$ and θ^{II} into Eq. (3).

The direct light reflected from the scene is almost completely attenuated when the observation distance is close to infinity which means there is only airlight component left. The total intensity of the image I at an infinite observation distance may be considered as the airlight from an object at an infinite distance A_{∞}. The degree of polarization of the airlight can be obtained by $p = (I^{\perp} - I^{\mathrm{II}})/(I^{\perp} + I^{\mathrm{II}})$. It should be noted that the estimation of p and A_{∞} is based on the hypothesis that the extinction coefficient $e^{-\beta z}$ of the sky region in the image is zero, under normal circumstances, aerosol of large radius like the water vapor particles will absorb the radiance and generate secondary radiance as light sources which means completely