

THE RS IMAGES RESTORATION OF CBERS-2 BASED ON ATMOSPHERIC MTF EVALUATION USING METEOROLOGICAL DATA

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ABSTRACT:

Atmospheric MTF(Modulation Transfer Function) takes a critical role in restoration of atmospheric blurred RS(Remote Sensing) images. This MTF can be determined by meteorological data. Among the existing deblurring methods of RS images, the meteorological data is not used in estimation of atmospheric MTF. For CBERS-02(China and Brazil Earth Resource Satellite) RS image data, a new deblurring algorithm is proposed. In this new method, both turbulence and aerosol MTFs are predicted via meteorological parameter measured at weather station on the time when and in the region where the RS image were recorded. The product of these two MTFs is used as the total atmospheric MTF which is combined with Wiener filter. Using the developed algorithm, turbulence blur, aerosol blur and path radiance contrast inconsistent are all corrected simultaneously. The area under MTF curve of restored image is apparent larger than one of original image. Experimental results with CBERS-02 RS images prove that the algorithm works well on restoration of atmospheric degraded images.

1. INTRODUCTION

With the increasing of ground resolution of modern satellite images, atmospheric turbulence effects to remote sensing images is more and more serious, especially over long atmospheric paths. The atmospheric degradation is caused by turbulence, scattering and absorption of particles and aerosols. The main influence of the turbulence over long exposures is to cause wave-front tilt, typically reach to amount of tens or even hundreds of micro-radians, which causes image shifts in the image plane. These image distortions can be partially compensated by either adaptive optics techniques or using short exposure to "frozen" atmospheric, which is less than the fluctuation time. Aerosol which changes very slowly could lead to light diffusion or scattering, while the large angle scattering causes attenuation and the small angle scattering leads to images blur.

The systemic methods for restoration blurred images caused by atmosphere components model the observed images as a convolution procedure between the original image and the atmospheric modulation transfer function(MTF). Given the MTFs and knowledge of the noise statistics characteristic, effective method deblurring atmospheric degraded images is deconvolution techniques. The advantages of these methods are simplicity, low cost and practical. Main difficulty of these methods is to obtain a reasonably correct atmospheric MTF shape on the time when and in the place where the image observed. One way to get the atmospheric MTF is to measure the images of a point, resulting in point spread function(PSF) of imaging system. MTF of system is the normalized absolute value of Fourier transform of the PSF.

Usually, the overall atmospheric MTF is essentially the product of the turbulence and aerosol MTFs. Models which describe the meteorological characters depended on refractive index structure coefficient C_n^2 and aerosol distribution has been developed¹.

Turbulence blur effects are simulated in both short and long exposure by MTFs². Besides the turbulence, there are scattering and absorption effects caused by molecules and aerosols in the atmosphere, which could lead to attenuation as well as blur. According to the Fourier optics theory, the blur effects caused by turbulence is mainly in high spatial frequency, just like a low-pass imaging system.

2. THE CALCULATED MODELS OF MTFs

2.1 The calculated model of turbulence MTF

In generally, the blur and tilt caused by turbulence in long exposure could be described perfectly with the formula¹:

$$MTF_{le} = \exp(-57.3\nu^{5/3}C_n^2\lambda^{-1/3}R) \quad (1)$$

Where, MTF_{le} is the long-exposure MTF, ν is the angular frequency, C_n^2 is the refractive index structure coefficient, R is the path length, and λ is the radiation wavelength.

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In the short exposure case, the turbulence tilt is removed and the turbulence MTF is evaluated from¹

$$MTF_{se} = \exp \left\{ -57.3v^{5/3} C_n^2 \lambda^{-1/3} R \left[1 - \mu \left(\frac{\lambda v}{D} \right)^{1/3} \right] \right\} \quad (2)$$

Where, MTF_{se} is the short exposure MTF, μ is 1.0 in the near field and 0.5 in the far field, and D is the aperture diameter.

2.2 The calculated models of aerosol MTF

On the other hand, the images attenuation and blur are caused by absorption and scattering produced by molecules and aerosols in the atmosphere. Unlike the turbulence in atmosphere, the angular blur due to aerosols is very wide, usually on the order of radians, which is typically order of magnitude wider than imaging field of view. The angular spread of incident scattered light is similar with diffraction limit λ/a , where a is the dominant particulates radius and λ is the radiation wavelength. This ratio is typically on the order of radian. The aerosol effects on a practical imaging system can be described by the practical instrumentation- based aerosol MTF, which can be approximate by the Gaussian form³:

$$MTF_a = \begin{cases} \exp[-A_a R - S_a R(v/v_c)^2], & v \leq v_c \\ \exp[-(A_a + S_a)R], & v > v_c \end{cases} \quad (3)$$

Where, MTF_a is the practical aerosol MTF, S_a and A_a are the atmosphere scattering and absorption coefficient, and v_c is the aerosol cut-off angular spatial frequency. S_a and A_a are dependent also on the instrumentation properties³.

3. EVALUATION OF THE ATMOSPHERIC MTF

3.1 The evaluation of the turbulence MTF

Since the overall atmosphere MTF is composed of both aerosol and turbulence effects, and each component is dependent on the time, date, type of ground surface and weather conditions.

Firstly, it is very useful to evaluate the refraction index structure coefficient C_n^2 according the Eqs (1) and (2) to obtain the turbulence MTF. Fortunately, a simple empirical model has been yielded to evaluate this parameter by U.S. Army Night Vision Lab through experiments. This model is based on standard meteorological parameters measured by the weather station. The value of C_n^2 is related to the hour of the day. It has high values at noon and has low values at morning and evening. A concept of temporal hour (th) has been defined to calculate

the C_n^2 simple. The duration of one th is obtained by subtracting the hour of sunrise from that of sunset and dividing by 12¹. The current th is obtained by subtracting the hour of sunrise from the current hour and dividing by the value of one th. Using this concept, a weight function was constructed. Considering the effects of aerosol, a more accurate empirical model to predict C_n^2 includes aerosol loading by the total cross-sectional area (TCSA) of the aerosol particulates in square centimetres per cubic meter:

$$\begin{aligned} TCSA = & 9.69 \times 10^{-4} RH - 2.75 \times 10^{-5} RH^2 \\ & + 4.86 \times 10^{-7} RH^3 - 4.48 \times 10^{-9} RH^4 \\ & + 1.66 \times 10^{-11} RH^5 - 6.26 \times 10^{-3} \ln RH \\ & - 1.34 \times 10^{-5} SF^4 + 7.30 \times 10^{-3} \end{aligned} \quad (4)$$

And

$$\begin{aligned} C_n^2 = & 5.9 \times 10^{-15} W + 1.6 \times 10^{-15} T - 3.7 \times 10^{-15} RH \\ & + 6.7 \times 10^{-17} RH^2 - 3.9 \times 10^{-19} RH^3 - 3.7 \times 10^{-15} WS \\ & + 1.3 \times 10^{-15} WS^2 - 8.2 \times 10^{-17} WS^3 + 2.8 \times 10^{-14} SF \\ & - 1.8 \times 10^{-14} TCSA + 1.4 \times 10^{-14} TCSA^2 - 3.9 \times 10^{-13} \end{aligned} \quad (5)$$

Where, W is the temporal hour weight, T is the air temperature, RH is the relative humidity, WS is the win speed, and SF is the solar flux in units of kw/m².

Values of regression coefficients are listed in the following table according to the Ref.2.

	Temporal hour interval	Relative weight W
	Until -4	0.11
Sunrise...	-4 to -3	0.11
	-3 to -2	0.07
	-2 to -1	0.08
	-1 to 0	0.06
	0 to 1	0.05
	1 to 2	0.1
	2 to 3	0.51
	3 to 4	0.75
	4 to 5	0.95
	5 to 6	1.00
	6 to 7	0.90
	7 to 8	0.80
	8 to 9	0.59
	9 to 10	0.32
	10 to 11	0.22
Sun set...	11 to 12	0.10
	12 to 13	0.08
	over 13	0.13

Table 1 weight function W

3.2 The evaluation of the aerosol MTF

The serious effect of aerosols to atmospheric blur in the remote sensing images has been introduced in the front section. The aerosol MTF is dependent on the aerosol size distribution. Furthermore, the aerosol MTF actually recorded in the image is usually affected also by the optical and photoelectric instrumentation⁴, in particular by the field of view, dynamic range, and angular spatial frequency bandwidth. The aerosol MTF prediction is concentrated on predicting the aerosol size distribution according to the weather status. Actually, the distribution of particles changes very sharply with weather. They give rise to small angle forward light scattering and cause image blur. A short description of the models is summarized in the Ref.4. The particle size distribution models are based on the Junge power-law distribution:

$$\frac{dn}{dr} = Ae^{-\alpha} \tag{6}$$

Where r is the particle radius and n is the number concentration. For general region,

$$\begin{aligned} \ln A = & -0.497 + 0.025RH - 0.00198\overline{RH} \\ & - 0.0000986\overline{RH}^2 - 0.0144WS - 0.331\overline{WS} \\ & + 0.0489\overline{WS}^2 + 0.0823T - 0.402SF \end{aligned} \tag{7}$$

And

$$\begin{aligned} \alpha = & 3.934 + 0.00831RH - 0.0172\overline{RH} \\ & + 0.000117\overline{RH}^2 - 0.0239WS \\ & - 0.179\overline{WS} + 0.00961\overline{WS}^2 \\ & - 0.0291T - 0.0201SF \end{aligned} \tag{8}$$

Where, \overline{RH} and \overline{WS} are the relative humidity and wind speed averaged over the previous 24 hour.

4. AN IMPROVED WIENER FILTER

The wiener filtering is a classical image restoration method based on the least mean error. In fact, the application of this method is more simply and effective. The Wiener method assumes the image and noise are generally a stable process. The evaluation formula of Wiener filter for images restoration through the DFT (discrete Fourier Transform) is :

$$F(u, v) = \frac{H^*(u, v)}{|H(u, v)|^2 + S_m(u, v) / S_{xx}(u, v)} G(u, v) \tag{9}$$

Where $S_m(u, v)$ and $S_{xx}(u, v)$ are the power spectral of noise and distortion image respectively.

It could be found that the Wiener filter is a kind of non-iterative filter from Eq.9. The mainly disadvantage of this method is that it can not incorporate the constraint limits into the restoration procedure. So, in this paper, an iterative Wiener method is adopted to improve the image restoration results.

Based on the classical Wiener filter, we assume an evaluated spectral of the real image $F_{old}(u, v)$. The restoration error in frequency domain is defined as:

$$S(u, v) = G(u, v) - F(u, v)H(u, v) \tag{10}$$

It is hoped that an improved new evaluation $F_{new}(u, v)$ exists to decrease the norm square $\|S(u, v)\|^2$ of restoration error. If defines $S_1(u, v) = G(u, v) - F_{old}(u, v)H(u, v)$, and then, the evaluation provide by Wiener filter could be rewritten as:

$$\begin{aligned} \tilde{F}(u, v) = & \frac{H^*(u, v)S_1(u, v)}{|H(u, v)|^2 + S_m(u, v) / S_{xx}(u, v)} \\ & + \frac{|H(u, v)|^2}{|H(u, v)|^2 + S_m(u, v) / S_{xx}(u, v)} F_{old}(u, v) \end{aligned} \tag{11}$$

It could be found that the fraction part of the second term is less than 1. Therefore, the new approximate evaluation of the real image spectral could be deduced as:

$$F_{new}(u, v) = F_{old}(u, v) + \frac{H^*(u, v)S_1(u, v)}{|H(u, v)|^2 + S_m(u, v) / S_{xx}(u, v)} \tag{12}$$

The improved wiener filter provides an iterative image restoration method, and the prior knowledge about the images and the blur factor are incorporated into the iterative process to ensure the correct and quick iteration procedure. The flow chart of this method is showing in Fig 1.

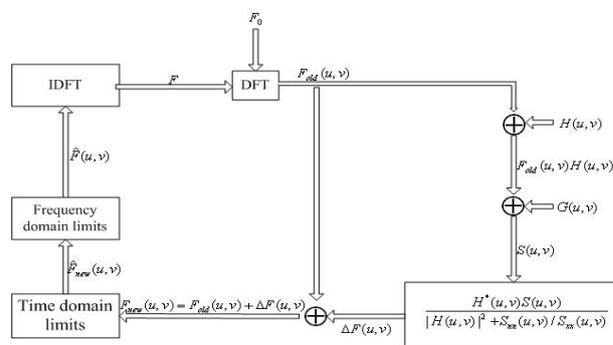


Figure. 1 The flow chart of improved Wiener filter method

5. EXPERIMENT AND RESULT ANALYSIS

The degradation procedure is estimated by the predicted atmospheric MTF using the expressions (1)~(8). And then, the restoration process is performed using the iterative Wiener filter introduced in the section 4. In the prediction of atmospheric MTF, the product of turbulence and aerosol MTFs is taken as the average atmospheric MTF. The variance in the turbulence MTF is considered as a noise term besides the system noise. The high spatial frequency enhancement is optional, and in particular the frequency is less effected by turbulence variance as well as system noise.

One of the experiment results is shown in Fig.(2) and Fig(3). The Fig.(2) is one part of remote sensing image observed by CBERS-2(China and Brazil Earth Resource Satellite) on 2006.5.19. The meteorological data and imaging time needed for the restoration algorithm are listed in table (2).The result shows that the restoration from atmospheric blur is so complete that individual pixels are seen in the restored image. The weather predicted overall atmospheric MTF derived from both aerosols and turbulence through the weather parameter which listed in the table (2) is used in the presented iterative Wiener restoration method. Comparing the restored image and the original image shown in Fig (3) and Fig(2) respectively, it is found that, since atmospheric effects were reduced in the restored method, the minimal resolvable contrast in Fig(3) was significantly improved.



Figure 2 the observed blurred image

Sunrise time	5:05	Sunset time	18:47
Average temperature °C	27.1	Imaging time	11:57
Wind speed (m/s)	2	Relative humidity (%)	39
Solar flux (kw/m ²)	0.45	Visibility distance (m)	12000
Wavelength(m)	5×10 ⁻⁷	Imaging region	ChengDu
The date	2006.5.19		

Table 2. the weather parameter on the imaging time



Figure 3 the restoration image using this paper method

One criterion for the restoration quality is the ratio between the areas under the MTF curves (MTFA) after and before restoration. The MTFs shown in the Fig 4 were extracted from the image using the edge response between the white and black stripes in the bar target. The edge-response derivative is the line spread function in the image. The system MTF was calculated by the Fourier transforming the LSF.

The ratio between the areas under the image MTF curves after restoration and before restoration is 1.89. The result shows that the method presented in this paper is effective for the remote sensing images degraded by atmospheric components including the turbulence and aerosols.

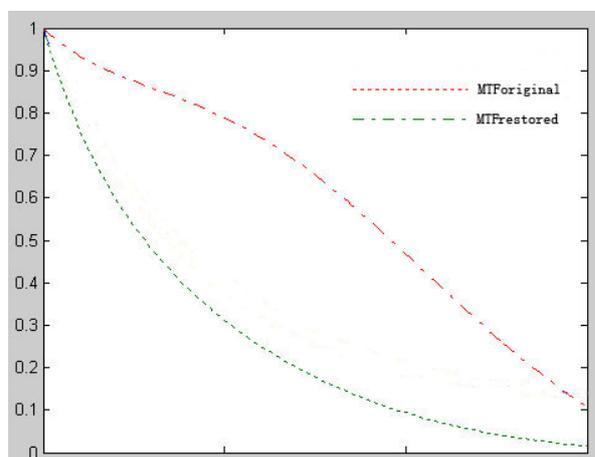


Figure 4 the MTFs of original and restored image

6. CONCLUSION

The probability of realizing remote sensing images restoration degraded atmospheric turbulence, base on the observed weather parameter and instrument parameter, is shown in this paper. Practical experiments are performed using the real remote images observed by CBERS-2.

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