Restoration of Landsat-7 Images

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Abstract –The image restoration problem attempts to recover images that have been degraded by the limited resolution of the sensor as well as by the presence of noise. The resolution of images obtained by the satellite sensors is degraded by sources such as: optical diffraction, detector size and electronic filtering. Therefore, the effective resolution is, in general, worse than the nominal resolution that corresponds to the detector projection on the ground. Through restoration techniques, it is possible to improve image resolution up to a certain level. This paper presents an evaluation of the effective spatial resolution of the ETM+ images and a methodology to restore them. The restoration algorithm is based on the method of the transfer function compensation. This article also shows that the restoration process combined with the resampling process can generate interpolated ETM+ images with good visual quality.

Keywords: restoration, image, ETM+, MTF, EIFOV, spatial resolution, interpolation.

1. INTRODUCTION

In digital image processing there is often a need to interpolate an image. Examples occur in scale magnification, image registration, geometric correction, etc. On the other hand, an image can be subject to several sources of resolution degradation and an improvement of this resolution may be necessary. Therefore, the interpolation and restoration can be combined in a single operation in order to generate images with a better effective spatial resolution over a grid that is finer than the original sampling grid.

The image restoration process can be regarded as a spatial filtering process, with the restoring filter being designed to compensate the degradation of the imaging system. The combination of the restoration and the interpolation processes in a single operation consists in modifying the ideal low-pass interpolation filter to take into account the restoration process. The restoration technique used in this work is the Modified Inverse Filter (MIF). The MIF is an approximation of the inverse filter that attempts to control the ill-conditioning problems that are inherent to the inverse filter. This technique has been already used to restore images of TM-5 and SPOT (Fonseca et al, 1993). This algorithm was implemented in the geographic information system (SPRING), developed by the image processing division at National Institute for Space Research (Camara et al, 1996), which has been used satisfactorily in various remote sensing applications.

For each band of the ETM+, the effective spatial resolution is calculated. Using this information and modeling the ETM+ modulation transfer function as a Gaussian function, the combined restoration-interpolation method is implemented and used to resample images from the Enhanced Thematic Mapper of the Landsat-7 (ETM+). Some results of restoration for ETM+ images are presented in the section 4.

2. ETM+ EFFECTIVE SPATIAL RESOLUTION

The Landsat-7 was launched on April 15, 1999. The Landsat-7 Enhanced Thematic Mapper Plus (ETM+) sensor continues the Landsat series that begun with the launch of Landsat 1 in 1972. It was predicted that optical performance, measured by the modulation transfer function (MTF), would change on-orbit as a result of exposure to the space environment. Some techniques were developed to monitor the along and cross-scan MTF performance of the ETM+ sensor system using images of ground targets (bridge) (Storey, 2001). The ETM+ modulation transfer function at the Nyquist frequency and the full width at half maximum point of the point spread function were computed from the best-fit system transfer function model. It was shown that the panchromatic band was the most sensitive to changes in ETM+ optical performance.

The original Landsat-7 MTF was specified to exhibit value greater than 0.275 at the Nyquist Frequency, in both the along and cross-scan directions (NASA, 1996). The model prediction indicated that panchromatic band would exhibit modulation below the 0.27 specification limit at Nyquist. Then, this limit was reduced to a value of 0.17 modulation at Nyquist frequency for the panchromatic band only.

In order to compute the ETM+ modulation transfer function, Storey (2001) adopted the same model used by Markham (1995). This model considers that the system has three components: 1) an optical model treated as a gaussian blur; 2) a detector model assumed as a rectangular pulse, and 3) an electronic filter modeled as a four pole low pass Goldberg filter. Fig. 1 shows the transfer function modulation of each component and the system transfer system calculated from design values. The values of the MTF specified in the sensor project (on-ground MTF) for three frequencies, normalized in relation to the Nyquist frequency, for each band are shown in Table 1. The MTF value at Nyquist frequency for the panchromatic band was relaxed to 0.17.

In order to evaluate the system on-orbit MTF, Storey (2001) used many scenes of the Lake Pontchartrain test area that were acquired, processed and analyzed over the first two years of the Landsat-7 mission (3/2/1999 through 6/16/2001). The MTF parameters were estimated based on model proposed by Storey (2001). For each band, the MTF at Nyquist frequency and the width of the PSF were calculated and used to evaluate the system performance.

In order to determine the effective spatial resolution of a sensor, it is usual to define a parameter called EIFOV (Effective Instantaneous Field of View). The EIFOV is defined as a function

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of the sensor MTF. Therefore, the EIFOV value can be defined as a function of the frequency in which the MTF is equal to 50% of its maximum value. The EIFOV parameter enables a comparison between different sensors with similar nominal spatial resolution.

Table 2 shows the EIFOV values, in the along (y) and cross-scan (x) directions, obtained from on-orbit MTF, for each band of ETM+ sensor.

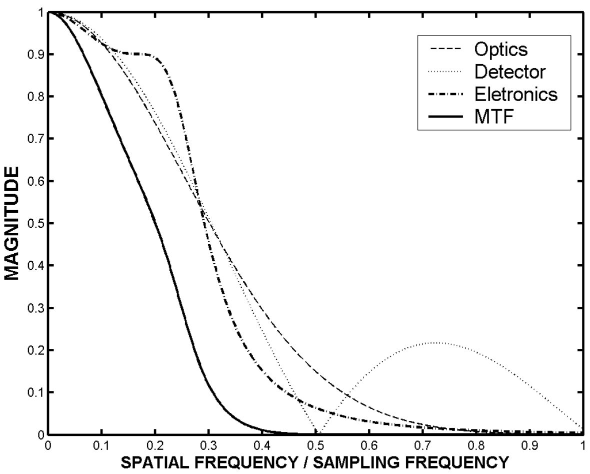

Figure 1. Modulation Transfer Function model components.

Spatial frequency/Nyquist	0.5	0.67	1.00
Bands 1-5 and 7	0.692	0.551	0.275
Band 6	0.613	0.495	0.236
Band 8 (PAN)	0.627	0.461	0.170

Table 1. ETM+ on-ground MTF.

Bands	EIFOV(x)	EIFOV(y)
Band 1	35.35	31.25
Band 2	36.15	33.10
Band 3	37.40	33.42
Band 4	39.16	34.74
Band 5	34.56	34.74
Band 7	33.40	31.13
panchromatic	23.94	21.03

Table 2. EIFOV values (in meters) for ETM+.

Fonseca et al (1993) have presented EIFOV values for Landsat-5 TM sensor: 41.6 (cross-scan) and 45.4 (along-scan) for bands 1-4 and 40.5 (cross-scan) and 45.4 (along-scan) for bands 5 and 7. Comparing ETM+ and TM-5 EIFOV values, one can observe that the effective spatial resolution of the ETM+ sensor is better than the one of the TM-5 sensor. This implies that the ETM+ images present better visual quality than TM-5 images.

3. RESTORATION FILTER

The restoration filter used in this paper is the Modified Inverse Filter (MIF), also called Transfer Function Compensation, which approximates the inverse filter and at the same time attempts to control the problems associated to it (Fonseca et al, 1993). The MIF is designed in the frequency domain and implemented in the spatial domain, as a Finite Impulse Response (FIR) two-dimensional, separable filter along the rows and the columns of the image. The restoration filter expressed in the frequency domain, P, is

$$\begin{cases} P(u) = \dfrac{D(u)}{H(u)} & |u| \leq u_c \\ 0 & \text{otherwise} \end{cases} , \qquad (1)$$

where: D = desired function as the response of the sensor,
H = Modulation Transfer Function of the sensor,
u = frequency,
u_c = cut-off frequency of H.

The design of the MIF filter requires knowledge of the sensor MTF. In the present work, the transfer function for ETM+ was approximated as a separable Gaussian function

$$H(u) = \exp\left(-Ku^2\right) \quad , \qquad (2)$$

where u is the normalized frequency with respect to the sampling frequency u_s, and K a function of the Effective Instantaneous Field of view (EIFOV):

$$K = 4 \cdot \ln(2) \cdot u_S^2 \left(EIFOV\right)^2 \quad . \qquad (3)$$

The EIFOV values used to calculate the ETM+ MTF are those defined in Table 2.

In digital image processing, the technique that is used to estimate sample values of an image over a desired grid, from samples over the original grid, is known as resampling. Conventional techniques such as the Nearest-neighbor, Bilinear and Parametric Cubic Convolution (PCC) have been used by remote sensing community in order to perform this interpolation process.

On the order hand, the interpolation process can also be regarded from the digital signal processing point of view (Crochiere and Rabiner, 1983). Using the multi-rate signal processing approach, the interpolation process has been combined with the restoration process in a single process which has been efficiently performed by a FIR filter of 11 pixels size along the rows and the columns of the image (Fonseca et al, 1993; Boggione, 2003).

ETM+ images were restored in a grid that is finer than the original sampling grid and compared to images interpolated by PCC interpolator. Some of these results are shown in the next section.

4. RESULTS AND DISCUSSION

In order to illustrate the performance of the restoration filter some results are shown below. The ETM+ images used in this experiment were taken from an urban region near São José dos Campos (Paraiba Valley), Brazil (path/row 218/76), dated of 8/19/2002.

Fig. 2 shows a color composite images of bands 3, 4 and 5 (3B4G5R) covering an area of 8.58 km x 5.16 km (pixel size =30m). All images were processed and extracted from larger images (full scenes). Each band was restored in a grid of 10 meters and combined in a RGB composite as one can see in Fig. 4.

Fig. 3 shows the image interpolated by PCC in a grid of 10 meters. One can observe that the restored image (Fig. 4) presents better visual quality than the PCC interpolated image (Fig. 3).

Figure 2. Original ETM+ image – Color composite 3B4G5R with pixel size of 30m.

Figure 3. ETM+ interpolated image– Color composite 3B4G5R with pixel size of 10 m.

Figure 4. Restored ETM+ image – Color composite 3B4G5R with pixel size of 10 m.

Fig. 5 shows the original ETM + panchromatic image with pixel size of 15 m, covering an area of 5.14 km x 3.43 km. Fig. 6 and Fig. 7 show the PCC interpolated and restored images in a grid size of 7.5 meters, respectively. Again, one can notice that the restored image presents better visual quality than the PCC interpolated image.

The variance values of the restored and interpolated images were also calculated and presented in Table 3. One can observe that restored images have greater variance values than PCC interpolated images, which implies that restored images contain more information details. Besides, one can also observe that the PCC interpolation process blurs the image so that its variance is smaller than the one of the original image.

Figure 5. Original ETM+ panchromatic band with pixel size of 15 m.

Figure 6. PCC interpolated ETM panchromatic band with pixel size of 7.5 m.

Figure 7. Restored ETM+ panchromatic band with pixel size of 7.5 m.

Bands	Method	Variance
Band 3	Original	325.08
	PCC	311.16
	Restoration	369.79
Band 4	Original	381.42
	PCC	360.62
	Restoration	465.26
Band 5	Original	852.05
	PCC	807.12
	Restoration	990.36
Band Pan	Original	97.81
	PCC	94.47
	Restoration	118.81

Table 3. Variance values for restored and PCC interpolated images.

5. CONCLUSION

This paper has presented an evaluation of the effective spatial resolution of the ETM+ images and a methodology to restore and interpolate them in a single operation. The method was implemented in Visual C++ and the software is available on request. The restoration filter has been satisfactorily used in various remote sensing applications such as urban and rural zoning and environmental monitoring.

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