METHOD FOR COMBINED IMAGE INTERPOLATION-RESTORATION THROUGH A FIR FILTER DESIGN TECHNIQUE

FONSECA, Leila M. G. - Researcher
MASCARENHAS, Nelson D. A. - Researcher
Instituto de Pesquisas Espaciais - INPE/MCT - DPI
C.P. 515 - 12201, São José dos Campos, SP, Brazil
Commission III

ABSTRACT

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, this image can be subjected to several sources of resolution degradation and an improvement of this resolution may be necessary. Therefore, this paper addresses the problem of combining the interpolation and the restoration in a single operation, thereby reducing the computacional effort. This is done by means of a 2D, separable, FIR filter. The ideal low-pass FIR filter for interpolation is modified to account for the restoration process. The Modified Inverse Filter (MIF) is used for this purpose. The proposed method is applied to the interpolation-restoration of Landsat-5 Thematic Mapper data. The later process takes into account the degradation due to optics, detector and electronic filtering. A comparison with the parametric cubic convolution interpolation technique is made.

I - INTRODUCTION

Images obtained by satellite sensors are affected by several degradation sources: optical diffraction, detector size and electronic filtering play an important role on the degradation of the image resolution. As a consequence, the effective resolution is, in general, worse than the nominal resolution, that corresponds to the detector projection on the ground and does not take into consideration the sensor imperfections (1).

Through restoration techniques, it is possible to improve image resolution up to a certain level. This paper explores the idea of combining the restoration process with an interpolation process in order to generate images with a better resolution over a grid that is finer than the original sampling grid. Related papers in this area include those of Malaret (2),Kalman (3), Dye (4) and Wilson (5). The results have been satisfactory when compared to the conventional interpolation methods as the nearest neighbor, bilinear and cubic convolution.

In this work, the combined restoration-interpolation method is used to resample images from the Thematic Mapper sensor of the Landsat-5 satellite (size of the original pixel=30 m). An evaluation study of the restored images is made for all the bands, except band 6. The restored images are compared to the images that were interpolated through the Parametric Cubic Convolution (PCC) with α =-0.5 (6). The comparison is made by the following methods: (1)visually;(2)through the difference-image;(3)through the radiometric profile over an image row;(4)through statistical measurements;(5)through the two-dimensional Fourier analysis. A similar study was performed by kalman (3), who made a comparison between MSS images that were interpolated by standard cubic convolution and restored images using the algorithm that was developed by the Environmental Research Institute of Michigan (ERIM).

II- COMBINED METHOD OF INTERPOLATION AND RESTORATION

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 interpolation processes in a single operation consists in modifying the ideal low-pass interpolation filter to take into account the restoration process.

The used restoration technique 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 (1). The MIF is designed in the frequency domain and implemented in the spatial domain, as a FIR two-dimensional, separable filter of 10 pixels size along the rows and the columns of the image.

III - EVALUATION OF THE RESULTS

The 512x512 TM image that was used as a test in the study covers the Galeão International Airport, in Rio de Janeiro, Brazil, and was taken in August, 8th,1987. The original image has only skew geometrical correction.

The images (bands 1-4, 5 e 7) were resampled over a 15 m spaced grid through the restoration-interpolation method and the interpolation by PCC. In order to evaluate the restored images, these images were compared to the images that were interpolated by PCC through the methods of section I.

Visual Quality

Figures 1-3 correspond to the sequence of TM images (band 3) that display a comparison between the interpolated and restored images (512x512 pixels). The differences between the Figures 2 e 3 are mainly on the edges or objects that exhibit more contrast with respect to surrounding areas. Linear features appear more enhanced in the restored image.

The cubic convolution process attenuates the high frequency components of the image and, therefore, a more blurred image is obtained. On the other hand, the restoration process amplifies the high frequency components of the image and an image with sharper transitions is obtained.

One can also observe that street delineation is better in the restored image, although the enhancement of the Moiré effect (aliasing) is also more evident in the restored image. This effect is clear on the edges of the airport runways that, instead of being linear, appear in a sawtooth form. In the interpolated image this effect also appears, but in a less pronounced form. The greater Moiré effect in the restored image is due to the fact that the restoring filter amplifies the image high frequencies, that were flipped over low frequency bands (spectrum overlap) on the sampling process.

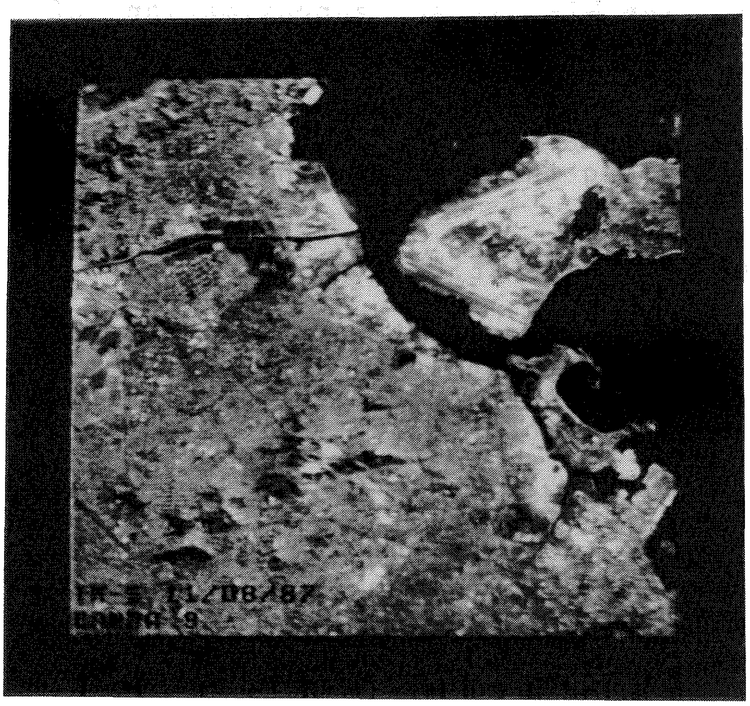

Figure 1: TM original image (512x512),band 3, covering the Galeão International Airport, pixel=30 m. A region of 256x256 pixels in the image was taken for resampling.

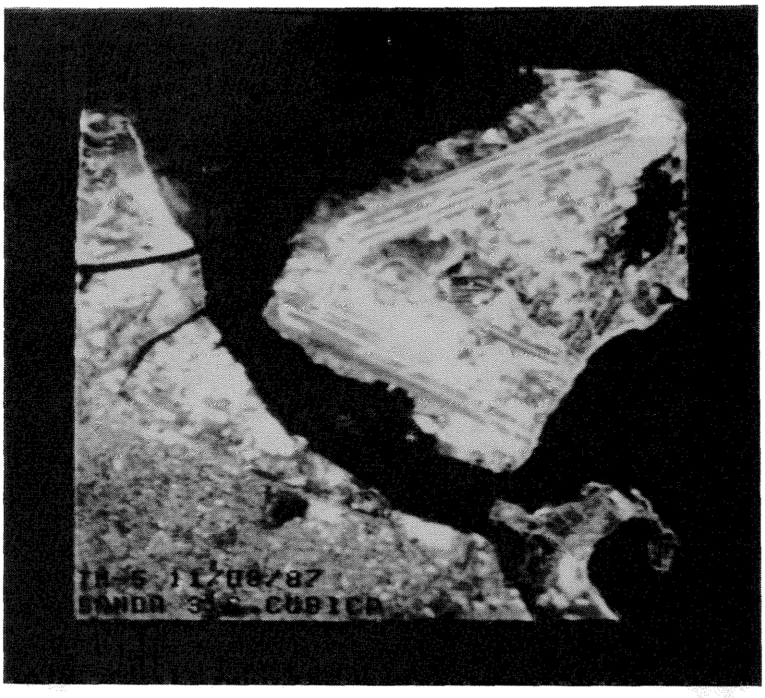

Figure 2: Interpolated image-cubic convolution, pixel = 15 m.

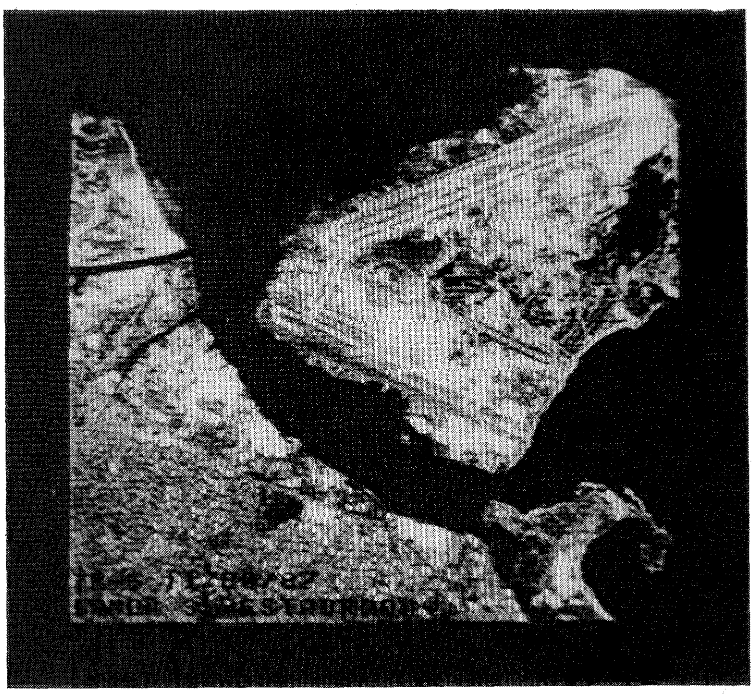

Figure 3: Restored image, pixel = 15 m.

Difference between Images

The difference images were obtained through a pixel-by-pixel subtraction (restored image - interpolated image). The largest differences occur on the edges between high contrast areas (airport runways), as it can observed through Figure 4.

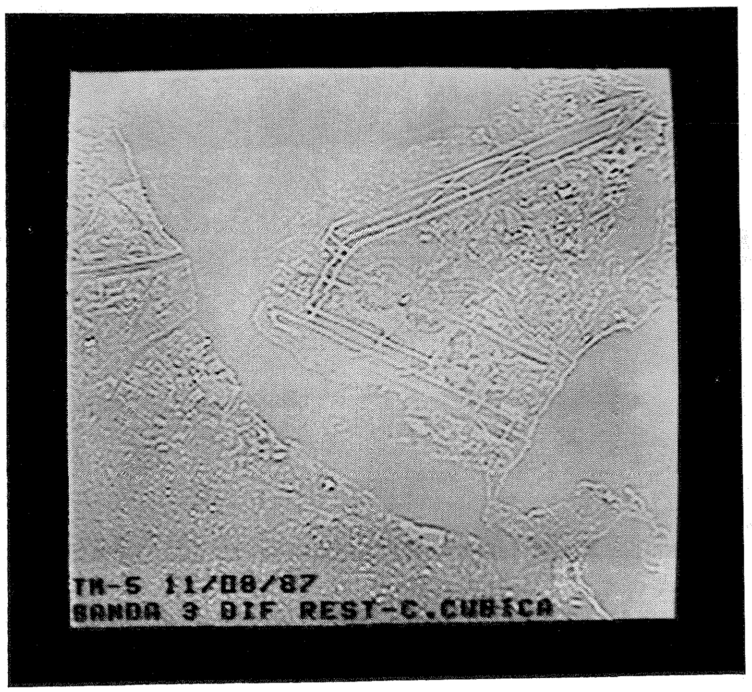

Figure 4: Difference image (band 3) with contrast stretch.

The cubic convolution process presents a blurring effect: the low pixel values corresponding to the dark side of an object are slightly increased and the high tones, corresponding to the bright side of the border, are reduced. The restoration process decreases the smoothing effect, produces sharper transitions on the edges and increases the overall sharpness of the image. These results are in accordance with the visual analysis.

Radiometric Profile

Radiometric profiles of the restored and interpolated images over a row (band 3) are displayed on Figures 5 and 6. One can observe that, where large peaks or valleys appear, the obtained values for restoration are, in general, more enhanced. In more uniform areas it was observed that the values of the restored images displayed small fluctuations where the interpolated image is approximately flat. This behavior can be explained by the blurring effect of the cubic convolution interpolator, as well as by the enhanced noise in the restoration, or even by information that is consistent with small visible details in aerial photographs (3).

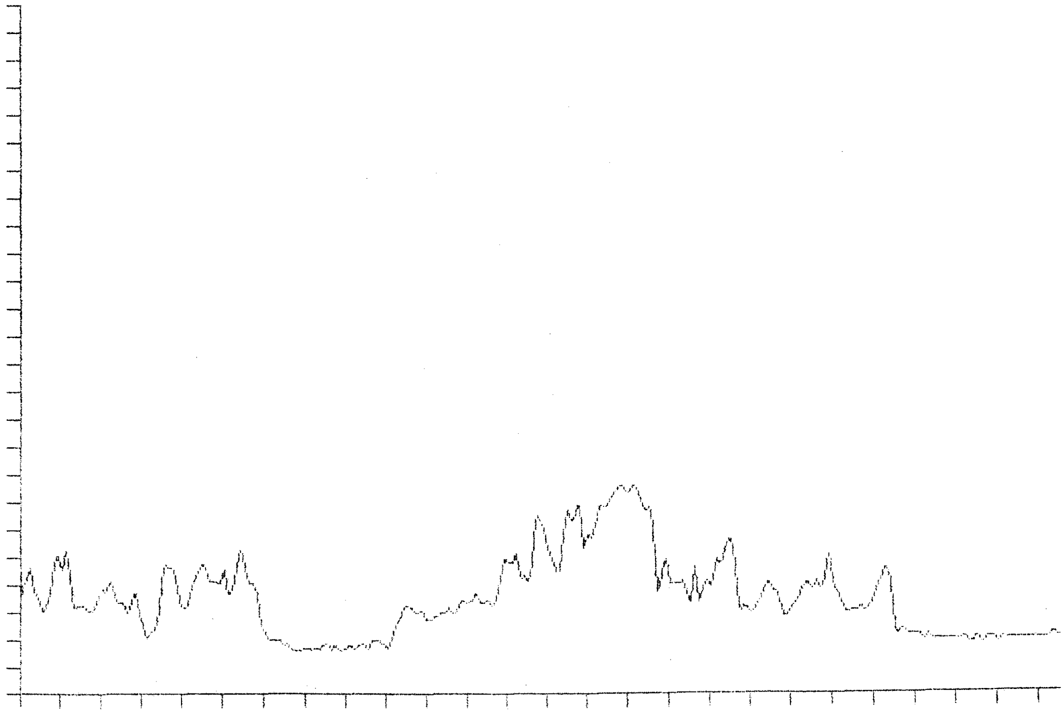

Figure 5: Radiometric profile of row 272 - Image (band 3) interpolated by PCC.

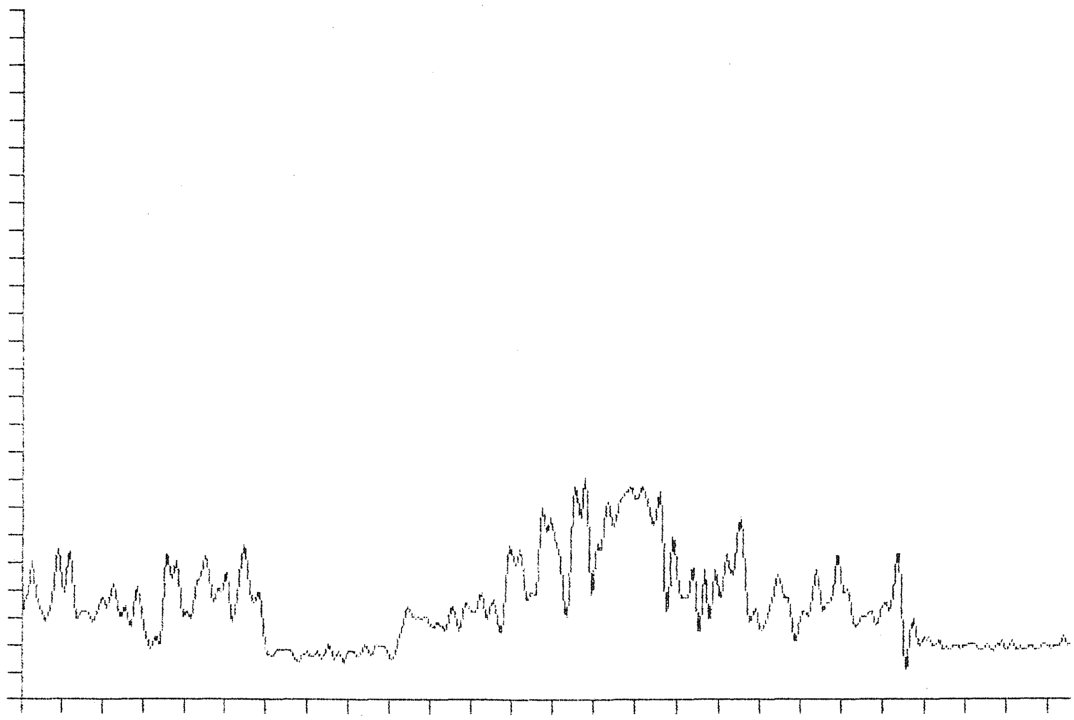

Figure 6: Radiometric profile of row 272 - Image (band 3) restored by MIF.

Statistical Measurements

The average values and the standard deviations of the restored and interpolated images were computed (Table 1). A region of 256 x 256 pixels with high contrast was selected for the data collection.

The results of Table 1 show that the average values obtained by the interpolated and restored images are virtually identical. This is due to the fact that the sums of weights of the interpolation and restoration filters are equal to one. This care was taken in order that the average value of the image should not change after the processing. However, the standard deviations for the restored images are larger than those obtained with the interpolated images. The difference is around 11% (bands 1-3) and 6% (bands 4, 5 and 7). This difference is a result of the smoothing due to the cubic convolution and the increase in the spatial resolution of the restoration process.

Tabela 1

Statistics of the Restored and Interpolated Images

Band		Statistical Parameters	
		Average Value	Standard Deviation
B1	C.Convolution	75.30	11.48
	Restored	75.27	12.98
B2	C.Convolution	34.70	9.12
	Restored	34.67	10.25
B3	C.Convolution	40.97	15.22
	Restored	40.94	17.08
B4	C.Convolution	38.42	13.87
	Restored	38.39	14.83
B5	C.Convolution	67.51	32.58
	Restored	67.51	34.35
B7	C.Convolution	22.96	14.73
	Restored	22.97	15.91

Fourier Analysis

A Fast Fourier Transform routine was used to compute the 2-D transform of a 256 x 256 pixels of the resampled image (band 3) by both methods. The ratio between the logarithms of the absolute values of the transformed restored and interpolated images was computed.

Figure 7 diplays the ratio-image (band 3) of the selected image, where the three colors represent three bands corresponding to different intervals of the ratio values:

Pink - $r < 0.95$
Yellow - $0.95 \leq r \leq 1.05$
Blue - $r < 1.05$

One can observe that the frequency content of the images using both resampling methods are approximately equal in the low frequencies region, as it was expected. In the meddle frequencies, the ratio is greater than one for a large band of the spectrum (blue region), since the frequency components amplitude of the restoration filter is greater than the PCC filter in the frequency band $|u| \leq 0.5$, as it is shown in Figure 8; in this region the frequency content of the restored image is greater than that of the interpolated image. This is an indication that the restored image has more details than the interpolated image.

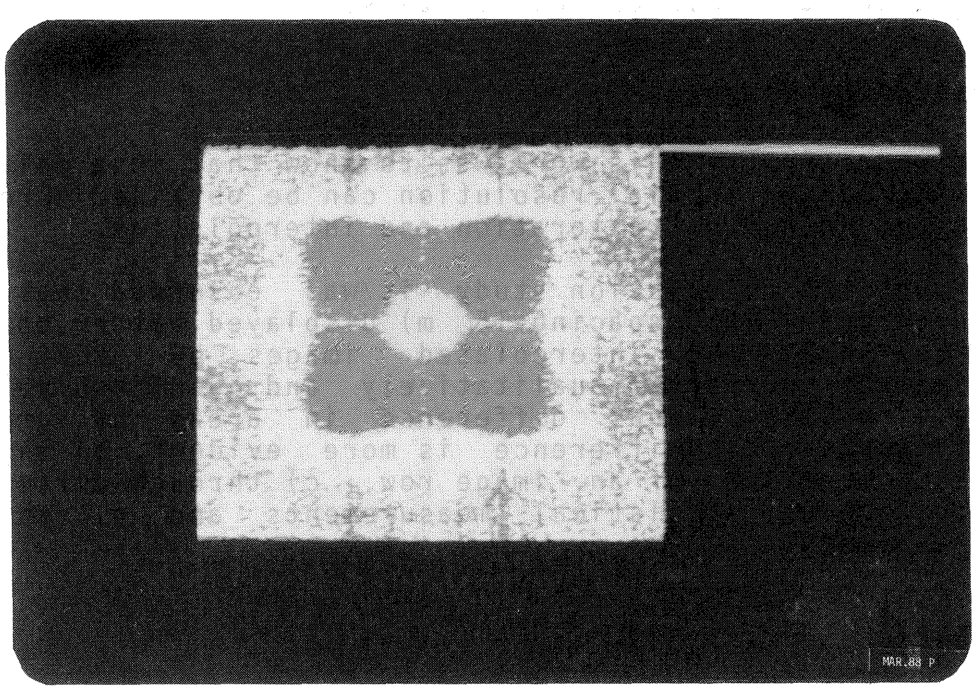

Figure 7: Ratio-image (restored)/(interpolated) of the Fourier Transform.

The pink band that appears close to the image boundary is a consequence of the fact that the PCC filter has a significant response beyond the cut-off system frequency,uc = 0.5 (see Figure 8). These components are responsible for the spectrum amplification of the interpolated image, in a region where it should have been eliminated by the interpolation filter, in the ideal situation.

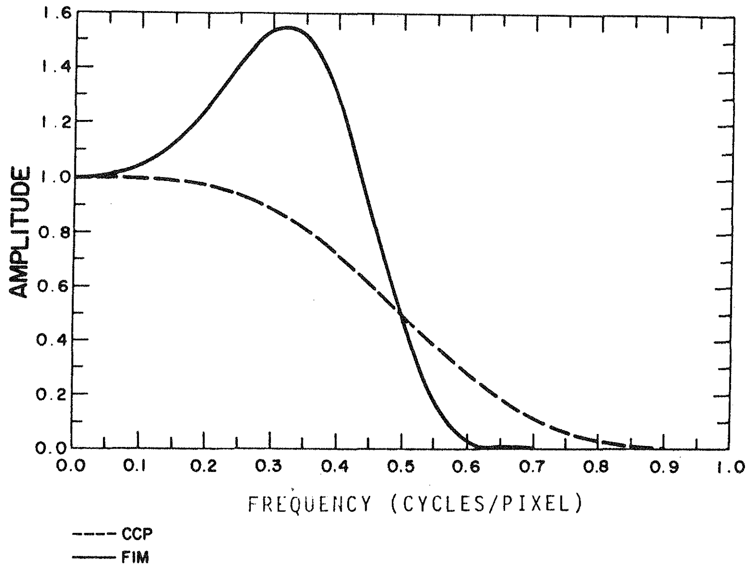

Figure 8: Spectra of MIF and PCC filters.

IV - CONCLUDING REMARKS

The objective of this work was to show that interpolated images with better spatial resolution can be obtained through the combined method of restoration and interpolation.

Through the evaluation study it was observed that the restored images (grid spacing=15 m) displayed better spatial resolution than the interpolated images by PCC. This evaluation was performed qualitatively and quantitatively a) by observing the visual difference in areas of greater contrast, where this difference is more evident, b) through radiometric profiles of an image row, c) through difference images ,d)through statistical measurements and e) through Fourier analysis.

V - REFERENCES

(1) FONSECA, L M. G. Restoration and resampling of Landsat satellite images through FIR filter design techniques. Master's thesis.S.J.Campos, Technological Institute of Aeronautics- ITA,Brazil,1988.(in portuguese)

(2) MALARET,E.R. Methods of image restoration for incoherent and coherent systems. Pd.D. thesis. West Lafayette,IN, Purdue University,School of Electrical Engineering,1985.

(3) KALMAN,L.S. Comparison of cubic-convolution interpolation and least-squares restoration for resampling Landsat MSS imagery.Unpublished notes.

(4) DYE,R.H. Restoration of Landsat images by two dimensional deconvolution. In:International Symposium on Remote Sensing of Environment, 10., Ann Arbor, MI, Oct. 6-10, 1975. PROCEEDINGS. Ann Arbor,ERIM,1975,p.725-730.

(5) WILSON,C.L. Image mapping software at ERIM; ANNUAL INTERNATIONAL USER'S CONFERENCE ON COMPUTER MAPPING HARDWARE, SOFTWARE,AND DATA BASES,Cambrige,MA,July 15-20,1979,21p.

(6) PARK,S.K.;SCHOWENGERDT,R.A. Image reconstruction by parametric cubic convolution. COMPUTER VISION,GRAPHICS, AND IMAGE PROCESSING,23(3):258-272,Sept.1983.