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RESOLUTION ENHANCEMENT OF ERTS IMAGERY\*

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I. ABSTRACT

A method is described for combined interpolation and enhancement of ERTS multispectral scanner data sets. Previous research has shown that good enhancement is most easily achieved when there are a large number of data points contained within the radius of gyration of the system point spread function. This requirement can be met using ERTS data by interpolating the data before enhancement. By varying the interpolation scale factor the data set can be empirically matched to a precalculated optimum restoration filter. Once the proper match of data and filter has been found the enhancement can be carried out directly or the enhancement and interpolation operations can be combined into a single filter thereby greatly reducing the processing time. Experimental results of applying this technique are shown along with more conventional methods of image interpolation and enlargement.

to be employed is strongly dependent on the particular problem parameters and the type of degradation being considered.

This research relates to an enhancement process applicable to the Earth Resources Technology Satellite's (ERTS) multispectral scanner (MSS) data.

III. DEGRADATION SOURCE

The ERTS scanner is an electro-optical device which scans transverse to the motion of the satellite and receives the radiant electromagnetic energy from the scene below. With this scanner is associated a two-dimensional impulse response or point-spread function (PSF), a cross-section of which is shown in Fig. (1). A spatially small or, ideally, an impulse input would result in such an output. The system performance would be satisfactory if only slow changes in the scanned field were present, but in general this is not the case.

If the input signal along one scan line was as shown in Fig. 2a, one would expect a blurring process to take place degrading the quality of the image considerably and resulting in poor resolution as shown in Fig. 2b. This blurring process would occur in two dimensions.

II. INTRODUCTION

IV. PROPOSED SOLUTION

The subject of image enhancement, using numerous techniques to upgrade the quality of the image, has been under intensive investigation for a number of years. Enhancement is required because of the fact that no physical picture generating system can faithfully and exactly reproduce the original scene. In any such process inevitable degradations occur, the extent of which depends on the quality of the reproducing system and on natural phenomena associated with the process. The output of an imaging system can often be processed further to offset some of the undesirable characteristics inherent in the system. The nature of enhancement

Based on what has been said so far, one might expect to alleviate this problem by developing an optimum restoration filter that could operate on the measured data. Methods have been developed for designing a processor that minimizes the width of the composite system point-spread function subject to constraints that prevent undesirable side effects from occurring that seriously affect image quality. The specific approach is to minimize the radius of gyration of the composite system subject to the following constraints:

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zeros at the points where interpolated values are to be computed and  $f(u)$  is the interpolated data set. The interpolator actually used is shown in Fig. 13 with a magnification factor of 12. Figure 14 shows the restoration function that has been used in the course of this development. It is interesting to look at these functions in the frequency domain. Figure 15 is the spectrum of the interpolation function. It is seen that there is rather strong amplification of low frequency components as well as modest amplification of high frequency components.

Figure 16 shows the spectrum of the convolved interpolation and restoration function. Note that in this figure high frequency components have been increased compared to Fig. 15. Figure 17 is the combined interpolation and correction function in the time domain.

## IX. EXPERIMENTAL RESULTS

In this section application of the enhancement technique to experimental data is considered and the results compared to more conventional methods of signal processing. The most frequently used methods of processing for examination of image detail are photographic enlargement in which each pixel is magnified and digital enlargement in which each pixel is repeated a number of times during image generation. A more refined approach makes use of some type of interpolation in which new points intermediate between the original data values are computed from the measured data.

For test purposes the upper left corner of Fig. 18, which is an ERTS image of the Battle Mountain area of Nevada, will be used. A  $4 \times 4$  photographic enlargement of this area is shown in Fig. 19 and a  $4 \times 4$  digital enlargement is shown in Fig. 20. An enlargement using cubic polynomial interpolation is shown in Fig. 21. The enhanced image is shown in Fig. 22. In this enhancement an enlargement of  $4 \times 4$  is employed to facilitate comparison with the other methods even though this leaves the scale factor error in the image.

Figure 19, which is the pure enlargement, gives the least satisfactory performance in that the image appears diffuse and blurred. The digitally enlarged image of Fig. 20 has a discontinuous appearance with abrupt changes in grey level. On close inspection it does not look "real". The interpolated image shown in Fig. 21 is a significant improvement over the enlargements and provides an improved image for recognizing details in the picture. Note that the linear features in the image are somewhat fuzzy. The enhanced image of Fig. 22 shows a further improvement in image resolution. The linear features have been narrowed and various closely spaced features are resolved into separate elements.

The same general scene is shown in Fig. 23 where a  $3 \times 4$  interpolation and enhancement has been carried out. In this image most of the scale factor difference between the x and y axes has been removed giving a geometrically corrected image.

As a further example of enhanced imagery, Fig. 24 and 25 show a  $3 \times 4$  interpolation and enhancement of the Washington, D.C. area in two different channels of ERTS data. It is seen that much detail can be observed in the enhanced images and that many familiar features such as the Pentagon, the monument reflecting pool and the Washington National Airport are clearly delineated.

## REFERENCES

1. Riemer, T.E. and C.D. McGillem, "Constrained Optimization of Image Restoration Filters," Applied Optics, Vol. 12, No. 9, Sept. 1973, pp. 2027-29.
2. Riemer, T.E. and C.D. McGillem, "Optimum Constrained Image Restoration Filters," LARS Information Note 091974, Laboratory for Application of Remote Sensing, Purdue University, W. Lafayette, Indiana.
3. Blackman, R.B. and J.N. Tukey, "The Measurement of Power Spectres," Doner, New York, 1959.
4. McGillem, C.D., "Interpolation of ERTS-1 Multispectral Scanner Data," LARS Information Note 022175, Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana.

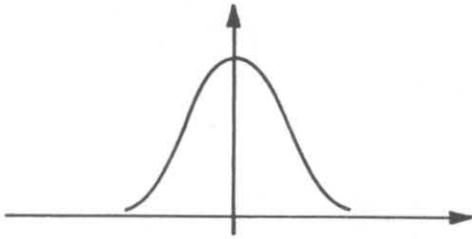


Figure 1. A Cross Section of MSS Scanner PSF

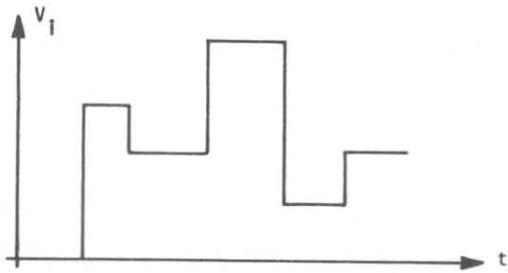


Figure 2a. A Fictitious Scan Line

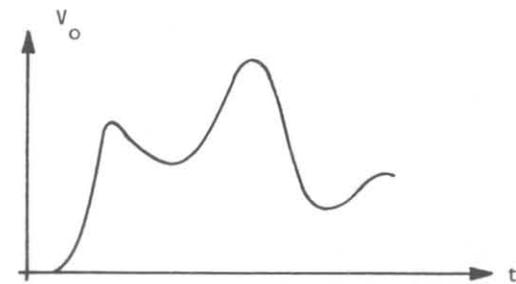


Figure 2b. Scanner Output with Figure 2a As Input Signal



Figure 3. Original ERTS Data Set in Washington, D.C. Area

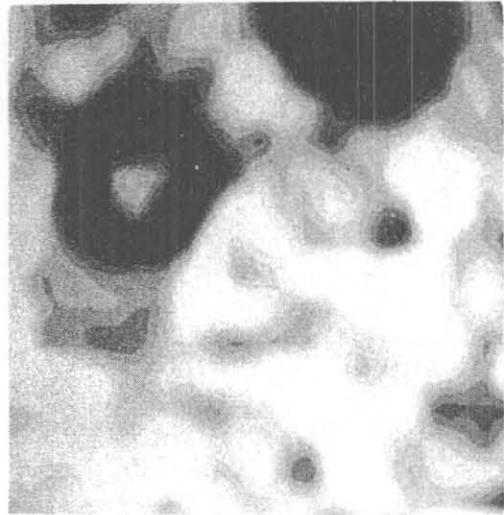


Figure 4. 17x12 Interpolation and 2x2 Digital Enlargement of Pentagon Area

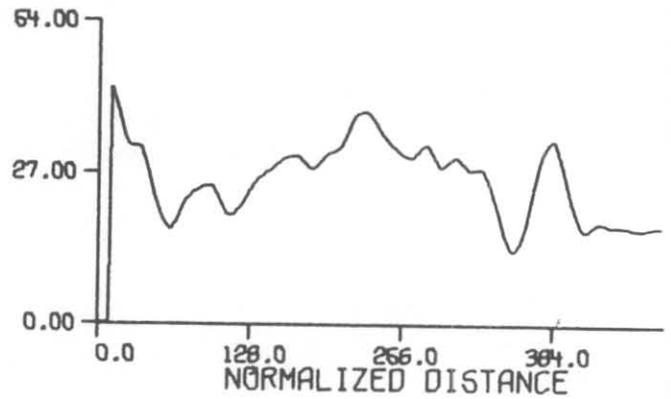


Figure 5a. A Scan Line Passing through Pentagon

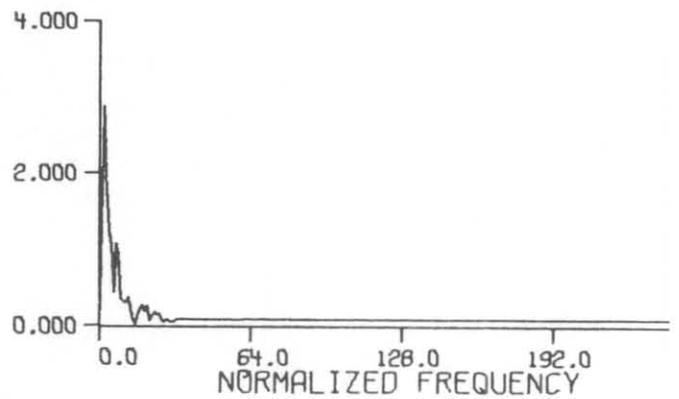


Figure 5b. Frequency Spectrum of Figure 5a



Figure 6. Enhanced Image of Pentagon Area



Figure 8. Enhancement of the Pentagon Area  
Using  $\phi_{nn}(f) = 10^{-4}$

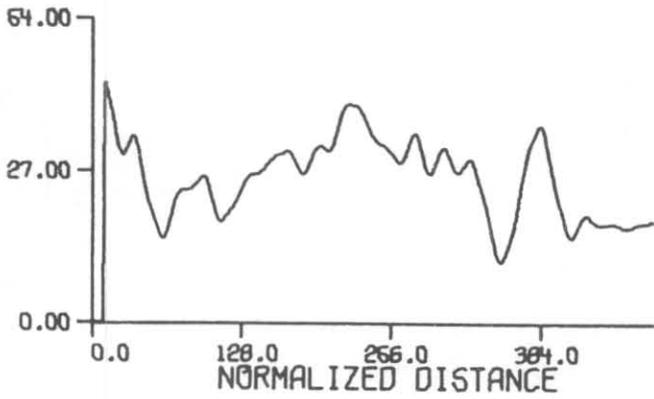


Figure 7a. A Scan Line Through the Pentagon  
in Enhanced Image

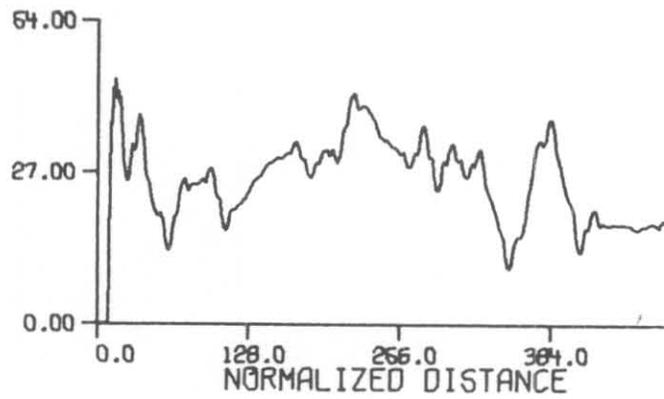


Figure 9a. Scan Line through Pentagon in Figure 8.

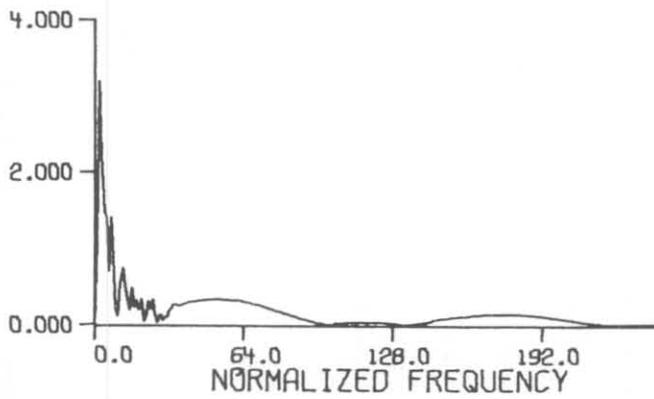


Figure 7b. Frequency Spectrum of Figure 7a

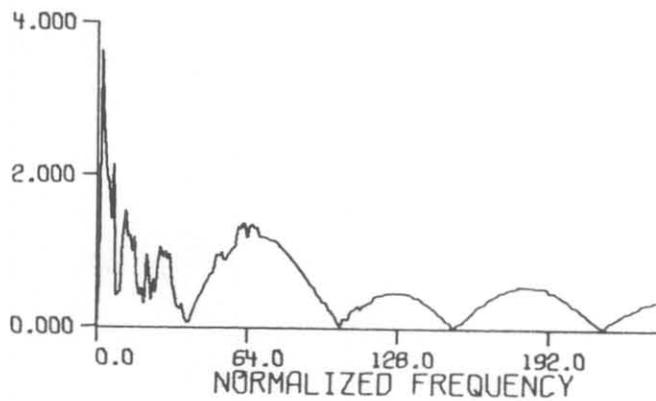


Figure 9b. Frequency Spectrum of Figure 9a

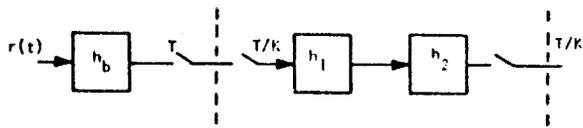


Figure 10. Model of the Enhancement Process

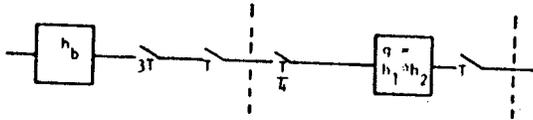


Figure 11. Model of Combined Interpolation/Enhancement

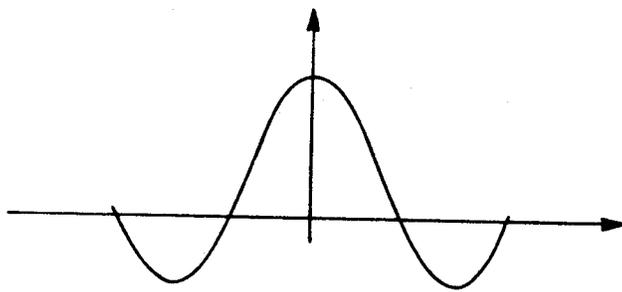


Figure 12. Form of the Interpolating Pulse

INTERPOLATING FUNCTION

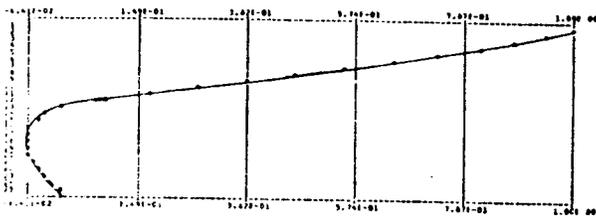


Figure 13. Interpolation Function used in the Enhancement Process (X dim)

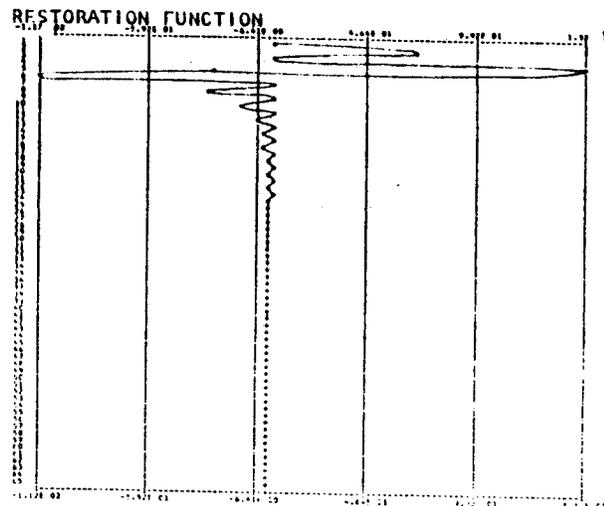


Figure 14. Restoration Function

MAGNITUDE OF INTERPOLATION SPECTRUM

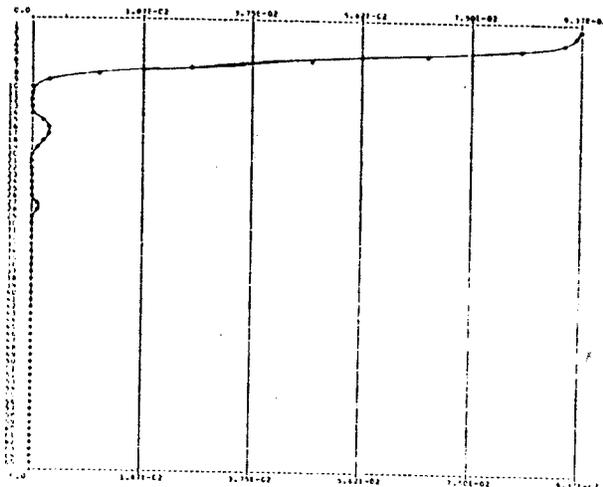


Figure 15. Spectrum of the Interpolation Function

MAGNITUDE OF COMPOSITE CORRECTION SPECTRUM

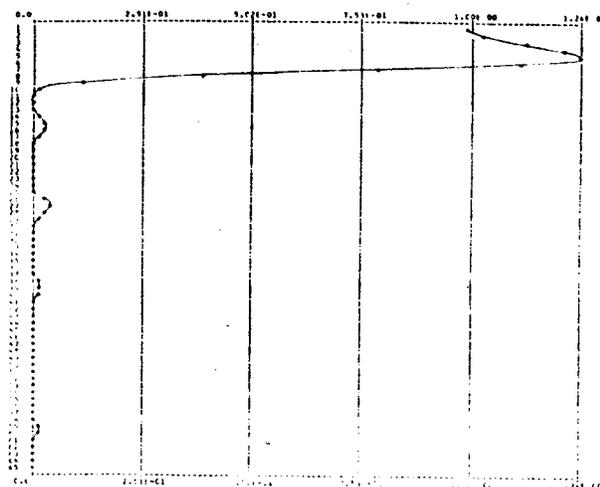


Figure 16. Spectrum of the Convolved Interpolation and Restoration Function

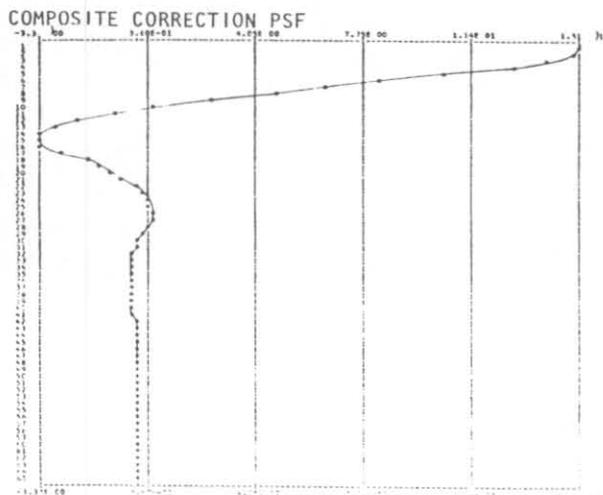


Figure 17. Combined Interpolation/Enhancement Filter Function

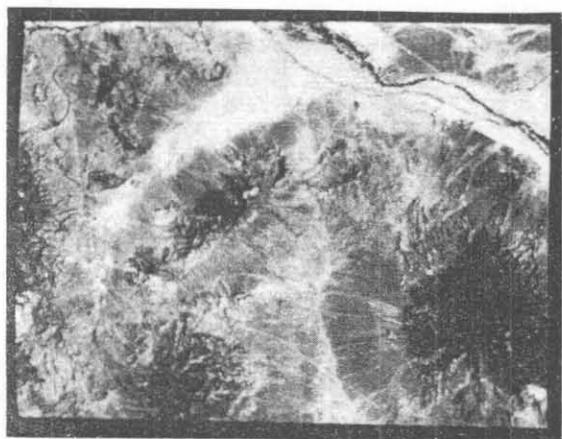


Figure 18. Test Area in Nevada (Band 5)  
(Upper left hand corner)

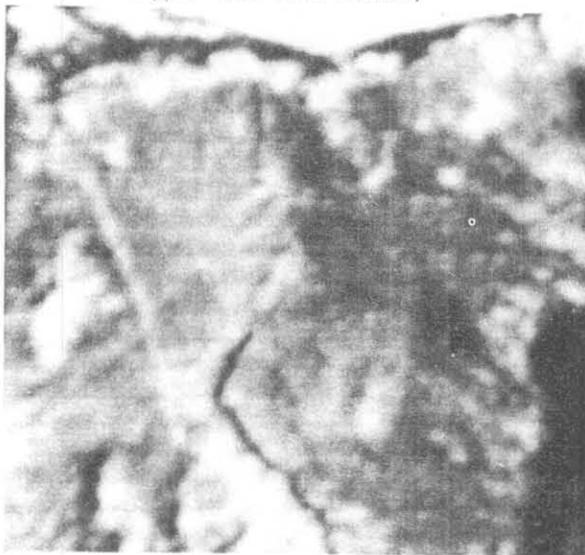


Figure 19. 4x4 Photographic Enlargement of Test Area

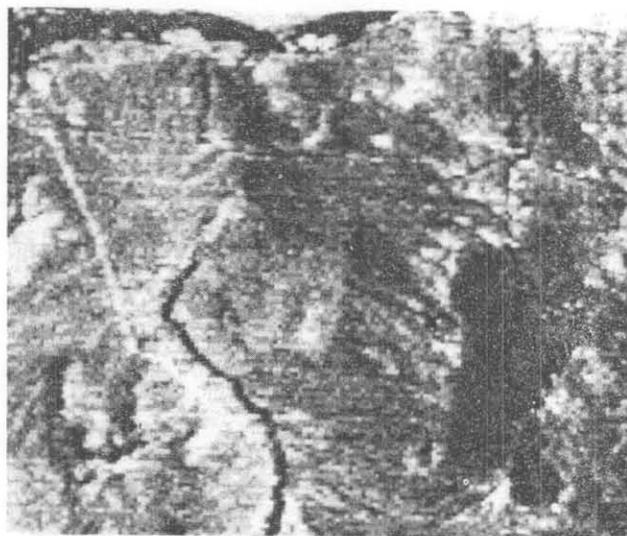


Figure 20. 4x4 Digital Enlargement of Test Area



Figure 21. 4x4 Interpolation of Test Area

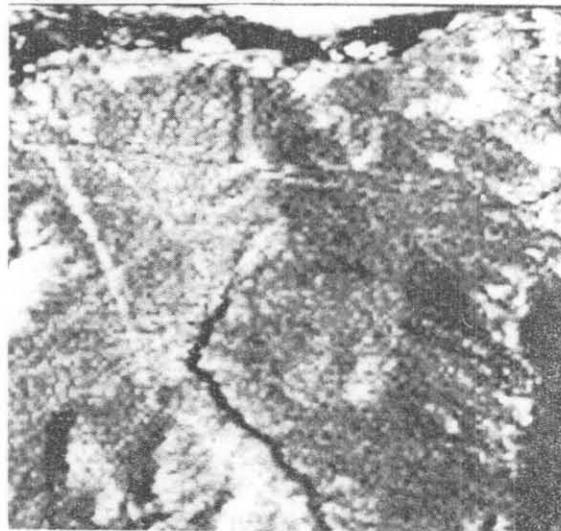


Figure 22. 4x4 Interpolation/Enhancement of Test Area



Figure 23. 3x4 Interpolation/Enhancement of  
150 Lines and 256 Samples of Test Area



Figure 24. 3x4 Interpolation/Enhancement of  
Washington, D.C. Area (Band 6)

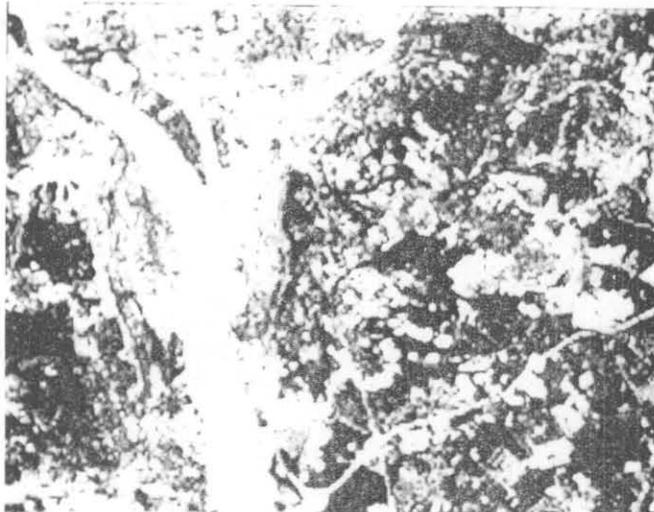


Figure 25. 3x4 Interpolation/Enhancement of  
Washington, D.C. Area (Band 5)