NASA-TM-86832

NASA Technical Memorandum 86832

NASA-TM-86832 19860011463

# Simulation of Landsat Multispectral Scanner Spatial Resolution with Airborne Scanner Data

Christine A. Hlavka



January 1986



NASA

National Aeronautics and
Space Administration

NASA Technical Memorandum 86832

# Simulation of Landsat Multispectral Scanner Spatial Resolution with Airborne Scanner Data

Christine A. Hlavka, Ames Research Center, Moffett Field, California

January 1986

National Aeronautics and
Space Administration

**Ames Research Center**
Moffett Field, California 94035

N86-20934#

SUMMARY

A technique for simulation of low spatial resolution satellite imagery by using high resolution scanner data is described. The scanner data is convolved with the approximate point spread function of the low resolution data and then resampled to emulate low resolution imagery. The technique was successfully applied to Daedalus airborne scanner data to simulate a portion of a Landsat multispectral scanner scene.

## INTRODUCTION

Satellite data is often simulated by using airborne scanner data in investigations into the utility of various imaging system characteristics. These investigations provide important information for the assessment of operational satellite data and the design of future imaging systems.

Daedalus Airborne Thematic Mapper (ATM) imagery was used to study the effects of Thematic Mapper (TM) characteristics on the accuracy of land use and land cover classifications (ref. 1). Seven ATM bands were configured to match TM bands 1-7. A mosaic showing portions of several flight lines was used to simulate a TM scene. This data set was systematically degraded to simulate multispectral scanner (MSS) imagery. Six other data sets combining MSS and TM characteristics were also generated so that all possible combinations of MSS or TM spatial, spectral, and radiometric resolutions could be tested.

The procedures for simulating MSS spatial resolution with ATM imagery will be described. Simulation of low spatial resolution is often achieved by boxcar filtering. (Each simulated low resolution pixel is given the average brightness value of a rectangular neighborhood of pixels on the high resolution data (refs. 2 and 3).) This degrades the resolution excessively, because too much weight is given to pixels away from the center of the instantaneous field of view (IFOV). An improved procedure described here uses published estimates of the modulation transfer function (MTF) of Landsat MSS to determine the optimal coefficients in a weighted averaging.

## SIMULATION OF LOW SPATIAL RESOLUTION

The object of an optical system such as a scanner can be represented as a continuous function $f(x,y)$, the radiation emitted and reflected at point $(x,y)$. The proportion of reflectance as a function $P(a,b)$ of distance $(a,b)$ from the center of a pixel is the system point spread function (PSF). If geometric distortions and noise are not present or are ignored, then the grey level is modeled as the convolution of $f(x,y)$ and $P(a,b)$:

$$g(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x - a, y - b)\cdot P(a,b)da\, db \tag{1}$$

Equation (1) implies that the PSF is constant over time and space, which is approximately true, although this may vary somewhat with changes in atmospheric conditions. For a more complete discussion of image formation, the reader is referred to Moik (ref. 4) and Schowengerdt (ref. 5).

The PSF of a scanner system has an approximately Gaussian shape (refs. 4 and 5):

$$P(a,b) = C\cdot \exp(-k_1\cdot a^2)\cdot \exp(-k_2\cdot b^2)$$

with $P(0,0) = C$ at the center and $P(WX,0) = P(0,WY) = C/2$, where:

$$WX = \sqrt{(-\ell n\ 0.5)/k_1} \quad \text{and} \quad WY = \sqrt{(-\ell n\ 0.5)/k_2}$$

are the half maximum points in the two directions.

An image $g(x,y)$ of coarse resolution can be simulated by using a fine resolution image $F(x,y)$ in place of $f(x,y)$ and performing discrete convolution:

$$g(x,y) = \sum_{i=-n}^{n}\sum_{j=-m}^{m} F(x - i, y - j)\cdot P(i,j) \tag{2}$$

with the numbers $n$ and $m$ chosen so that $P(i,j)$ is small outside the $(2n + 1)x(2m + 1)$ convolution window.

One may ask how fine a resolution is needed so that $F(x,y)$ approximates $f(x,y)$ sufficiently well for the simulation operation represented in equation (2). The high resolution grey-level value $F(x,y)$ is the convolution of $f(x,y)$ with the PSF of the high resolution system $P'(a,b)$. The low resolution grey value $g(x,y)$ can be expressed as the convolution of $F(x,y)$ with a relative PSF (ref. 6). The appropriate PSF is the inverse Fourier transform of the ratio of the MTFs of the scanners (ref. 6). If $P'(a,b)$ is Gaussian:

$$P'(a,b) = C'\cdot \exp(-k_1'\cdot a^2)\cdot \exp(-k_2'\cdot b^2)$$

then $P''(a,b)$ is also Gaussian:

$$P''(a,b) = C''\cdot \exp(-k_1''\cdot a^2)\cdot \exp(-k_2''\cdot b^2)$$

with $k_1'' = k_1 \cdot k_1'/(k_1 - k_1')$ and $k_2'' = k_2 \cdot k_2'/(k_2 - k_2')$. If the IFOV of the low resolution system is several times larger than that of the high resolution system, then $k_1' << k_1$ and $k_2' << k_2$, and thus $k_1''$ and $k_2''$ are approximately equal to $k_1$ and $k_2$.

Since convolution is a central-processing-unit-intensive computer operation, an alternative approach was considered. Low spatial resolution can be simulated in the Fourier frequency domain by multiplying the Fourier transform of the high resolution imagery by the MTF of the low resolution imagery, and then taking the inverse transform. This is often more efficient computationally (ref. 7), but software for Fourier processing is often limited to images whose dimensions are powers of two. If an image is inserted into a background image in order to create an image of allowable dimensions, great care must be taken to avoid "ringing" caused by discontinuities in brightness values (ref. 4). These difficulties are avoided in the convolution procedure, so it was adopted despite its inefficiency.

Equation (2) is implemented in three steps:

Step 1. Generate a Gauss filter with parameters WX and WY computed from the low resolution PSF, with C = 1.0, and large dimensions compared to the low resolution IFOV. This filter is used to compute the appropriate normalizing constant C and filter dimensions for the convolution filter. A simple rule is to use a central rectangular portion of the filter which retains all values of 0.10 or greater. The normalizing value C is recalculated as the inverse of the sum of values of the selected portion, so that the magnitude of the grey levels will remain approximately the same after convolution.

Step 2. The high resolution scanner data is convolved with this filter.

Step 3. The image is resampled using nearest neighbor grey-level values so that pixel spacings correspond to those of the low resolution imagery. Bilinear or bicubic resampling should not be used because the resolution would be broadened by the interpolation process.

## SIMULATION OF MSS WITH SCANNER DATA

Landsat MSS imagery was simulated by using Daedalus airborne Thematic Mapper imagery collected during a U-2 flight over central California. The IFOV of the scanner was 1.25 mrad, or 25 m at an altitude of 65,000 ft. Measurements on the imagery determined that pixel spacings were 17 m along scan and 22 m along track.

The PSF of Landsat was approximated using published results of Fourier analysis of MSS imagery (ref. 8). MTF values at multiples of approximately 1.5 cycles per kilometer were measured on graphs of the MTF as a function of frequency in the along-scan and along-track directions. These were fit to Gaussian curves by linear regressions of the logarithm of the MTF versus square of the frequency. The MTF was:

$$M(u,v) = M(u) \cdot M(v) = \exp(-0.0233 \cdot u^2) \cdot \exp(-0.0185 \cdot v^2)$$

where $u$ and $v$ are frequencies in the along-scan and along-track directions in cycles per kilometer. The PSF was calculated by taking the inverse Fourier transform of the MTF. This PSF was Gaussian with spread parameters:

$$k_1 = \pi^2/0.0185 = 532.5 \text{ km}^{-2} \quad \text{and} \quad k_2 = \pi^2/0.0233 = 424.4 \text{ km}^{-2}$$

$$WX = 36.1 \text{ m} \quad \text{and} \quad WY = 40.1 \text{ m}$$

These half maximum points are approximately half the 79 m IFOV of MSS.

## IMPLEMENTATION OF IDIMS

The software program, Interactive Digital Image Manipulation (IDIMS) (ESL Incorporated, Sunnyvale, California), was used to simulate low spatial resolution of MSS (ref. 9). IDIMS software for creating filters is normally used for filtering in the Fourier domain, therefore the half maximum points had to be converted to units of cycles per pixel. Let $WX'$ and $WY'$ be in units of ground distance (meters). Let the pixel spacings of the high resolution imagery be $dx$ and $dy$. The size of the filter was initially chosen to be 32 lines by 32 samples. The filter parameters for the IDIMS program GAUSS were:

$$WX = WX'/(ns \cdot dx) = 36.1/(32 \cdot 17) = 0.0665$$

$$WY = WY'/(nl \cdot dy) = 40.1/(32 \cdot 22) = 0.0582$$

$$DCGAIN = C = 1.0 \qquad HFGAIN = 0.0$$

$$NL = 32 \qquad NS = 32$$

All values outside of the 7×7 center of the resulting image were less than 0.10. The sum of values in the 7×7 center was 16.64, therefore C was recalculated to be 1/16.64 = 0.0601. The GAUSS program was rerun with DCGAIN = 0.0601 (keeping the other parameters the same), and the 7×7 center of the resulting image (see fig. 1) was used as the convolution filter. Convolution was performed by running the CONVOL program with the Daedalus data and the filter as input images.

The convolved image was resampled to approximate the MSS pixel spacings of 57 m × 57 m computer compatible tapes. Every fourth line and every third pixel was sampled to create an image with 68 m × 66 m pixel spacings using the MAGNIFY program with LINEFACT = 0.2500 (every fourth line) and SAMPFACT = 0.3333 (every third sample). A portion of the resulting simulated imagery is shown in figure 2(b). The resampling method is essentially nearest neighbor resampling. This method was chosen because it created an image of evenly spaced pixels with resolution defined nearest neighbor resampling to create average pixel spacings of 57 m × 57 m, by using LINEFACT = 22/57 = 0.3860 and SAMPFACT = 17/57 = 0.2982, would have resulted in an image with irregular sample spacings (ref. 7).

## DISCUSSION

The simulated MSS imagery was compared to a portion of a Landsat scene covering the same area. The resolution of the two pictures shown in figures 2(a) and 2(b) appeared to be about the same when examined on an interactive display. The simulated MSS was slightly more fuzzy than the MSS because the ATM data was convolved with the PSF of MSS rather than the PSF relative to the ATM sensor. Nevertheless, the simulation was judged an improvement over local averaging which had been used for simulation of Landsat MSS in the past.

The simulated imagery reduced the noise contained in Daedalus imagery because the convolution computation is a weighted average, and averaging decreases noise. Noise could have been added to the image to simulate the signal to noise ratio of the low resolution imagery. This was not done because noise characteristics of the ATM and MSS imagery were not well known. As a result, the simulated MAS imagery had a smaller noise component than real MSS data. This difference is particularly evident in figure 2 because of the diagonal striping pattern of the Landsat 4 MSS. This noise pattern is due to coherent noise in Landsat 4 sensors (refs. 10-12).

## REFERENCES


1. Acevedo, W.; Buis, J. S.; and Wrigley, R. C.: Changes in Classification Accuracy Due to Varying Thematic Mapper and Multispectral Scanner Spatial, Spectral, and Radiometric Resolution, Proceedings of the Eighteenth International Symposium on Remote Sensing of Environment, Paris, France, Oct. 1-5, 1984.

2. Alexander, D. A.; Buis, J. S.; Acevedo, W.; and Wrigley, R. C.: Spectral, Spatial, and Radiometric Factors in Cover Type Discrimination, Proceedings of the International Geoscience and Remote Sensing Symposium, Strasborg, France, Aug. 31-Sep. 2, 1983.

3. Williams, D. L.; Irons, J. R.; Markham, B. L.; Nelson, R. F.; Toll, D. L.; Latty, R. S.; and Stauffer, M. L.: Impact of Thematic Mapper Sensor Characteristics on Classification Accuracy, Proceedings of the International Geoscience and Remote Sensing Symposium, Strasborg, France, Aug. 31-Sep. 2, 1983.

4. Moik, J. G.: Digital Processing of Remotely Sensed Images, NASA SP-431, 1980.

5. Schowengerdt, R. A.: Techniques for Image Processing and Classification in Remote Sensing, Academic Press, 1983.

6. Digennaro, V.: Scale Effects: HCMM Data Simulation, Centro Studi ed Applicazione in Technologie Avanzate, NASA CR-163751, Nov. 1980.

7. Reeves, R. G.; Anson, A.; and Landen, D.: Manual of Remote Sensing, Vol. I, pp. 691-695.

8. Schowengerdt, R. A.; Antos, R. L.; and Slater, P. N.: Measurements of the Earth Resources Technology Satellite (ERTS-1) Multispectral Scanner OTF from Operational Imagery, Proceedings of the Photo-Optical Instrumentation Engineers, May 20-22, 1974, pp. 247-257.

9. VAX-IDIMS Functional Guide, ESL Incorporated, Sunnyvale, California, Sep. 1983.

10. Malial, W. A.; Metzler, M. D.; Rice, D. P.; and Crist, E. P.: Characterization of LANDSAT-4 MSS and TM Digital Image Data, IEEE Transactions of Geoscience and Remote Sensing, May 1984, pp. 177-191.

11. Bernstein, R.; Lotspiech, J. B.; Myers, H. J.; Kolsky, H. G.; and Lees, R. D.: Analysis and Processing of LANDSAT-4 Sensor Data Using Advanced Image Processing Techniques and Technologies, IEEE Transactions of Geoscience and Remote Sensing, May 1984, pp. 192-221.

12. Anuta, P. E.; Bartolucci, L. A.; Dean, M. E.; Lozano, D. F.; Malaret, E.; McGillen, C. D.; Valdes, J. A.; and Valenzuaela, C. R.: LANDSAT-4 MSS and Thematic Mapper Data Quality and Information Content Analysis, IEEE Transactions of Geoscience and Remote Sensing, pp. 222-236.

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.0025 | 0.0068 | 0.0124 | 0.0151 | 0.0124 | 0.0068 | 0.0025 |
| 0.0054 | 0.0146 | 0.0267 | 0.0326 | 0.0267 | 0.0146 | 0.0054 |
| 0.0085 | 0.0232 | 0.0422 | 0.0515 | 0.0422 | 0.0232 | 0.0085 |
| 0.0099 | 0.0270 | 0.0492 | 0.0601 | 0.0492 | 0.0270 | 0.0099 |
| 0.0085 | 0.0232 | 0.0422 | 0.0515 | 0.0422 | 0.0232 | 0.0085 |
| 0.0054 | 0.0146 | 0.0267 | 0.0326 | 0.0267 | 0.0146 | 0.0054 |
| 0.0025 | 0.0068 | 0.0124 | 0.0151 | 0.0124 | 0.0068 | 0.0025 |

Figure 1.- The convolution filter used to simulate MSS data with ATM imagery. This filter is the sampled point spread function of MSS.

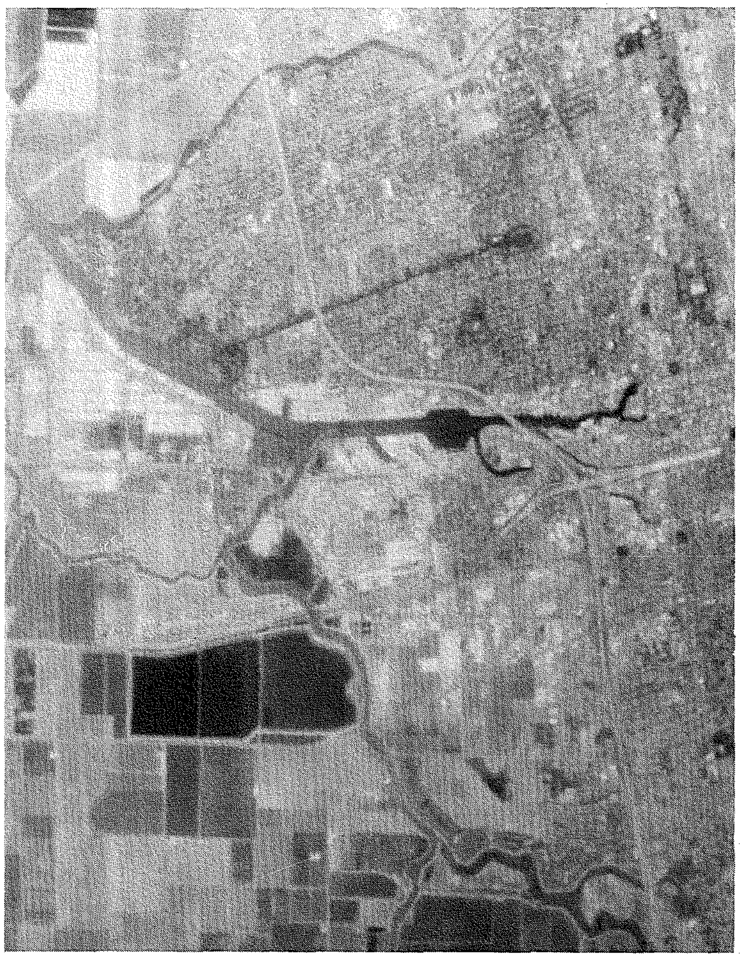

Figure 2.- (a) (left) ATM channel 3 coverage of the Stockton, California area. (b) (above left) Simulated Landsat MSS 4 created by convolving ATM channel 3 with the kernel in figure 1 and resampling. (c) (above right) Landsat MSS 4 coverage of the same area.

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| NASA TM-86832 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| SIMULATION OF LANDSAT MULTISPECTRAL SCANNER SPATIAL RESOLUTION WITH AIRBORNE SCANNER DATA | January 1986 |
| | 6. Performing Organization Code |
| 7. Author(s) | 8. Performing Organization Report No. |
| Christine A. Hlavka | A-85400 |
| 9. Performing Organization Name and Address | 10. Work Unit No. |
| Ames Research Center<br>Moffett Field, CA 94035 | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address | 13. Type of Report and Period Covered |
| National Aeronautics and Space Administration<br>Washington, DC 20546 | Technical Memorandum |
| | 14. Sponsoring Agency Code |
| | 668-14-04 |

15. Supplementary Notes

Point of Contact: Christine A. Hlavka, Ames Research Center, MS 242-4, Moffett Field, CA 94035, (415) 694-6060 or FTS 464-6060

16. Abstract

A technique for simulation of low spatial resolution satellite imagery by using high resolution scanner data is described. The scanner data is convolved with the approximate point spread function of the low resolution data and then resampled to emulate low resolution imagery. The technique was successfully applied to Daedalus airborne scanner data to simulate a portion of a Landsat multispectral scanner scene.

| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
|---|---|
| Multispectral band sensors<br>Airborne imagery<br>Satellite imagery<br>Spatial resolution<br>Optical systems | Unlimited<br><br>Subject category - 43 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
|---|---|---|---|
| Unclassified | Unclassified | 11 | A02 |

*For sale by the National Technical Information Service, Springfield, Virginia 22161

End of Document