LARS CONTRACT REPORT 021083

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QUARTERLY PROGRESS REPORT

FOR

LANDSAT-4 IMAGE DATA QUALITY ANALYSIS

FOR PERIOD INCLUDING

NOVEMBER 10, 1982 - FEBRUARY 8, 1983

NASA CONTRACT NAS5-26859

TO: NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT ROAD
GREENBELT, MD 20771

BY: P.E. ANUTA AND STAFF
PURDUE UNIVERSITY
LABORATORY FOR APPLICATIONS OF REMOTE SENSING
WEST LAFAYETTE, IN 47906-1399

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16. Abstract

This report describes progress on the Landsat-4 data quality study over the period November 10, 1982 - February 8, 1983.

Analysis during the quarter was carried out on geometric, radiometric, and information content aspects of both MSS and Thematic Mapper data. Test sites in Webster County, Iowa and Chicago, IL, and near Joliet, IL were studied. Band-to-band registration was evaluated and TM Bands 5 and 7 were found to be approximately .5 pixel out of registration with 1,2,3,4 and the thermal was found to be misregistered by 4 30m pixels to the east and 1 pixel south. Certain MSS bands indicated nominally .25 pixel misregistration. Radiometrically, some striping was observed in TM bands and significant oscillatory noise patterns exist in MSS data which is possibly due to jitter. Information content was compared before and after cubic convolution resampling and no differences were observed in statistics or separability of basic scene classes.

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Introduction

This report covers work done by LARS/Purdue under the referenced Landsat-4 Image Data Quality Analysis contract for the period November 10, 1982 through February 8, 1983. In this period, a large quantity of Thematic Mapper and MSS data was received and extensive evaluation was carried out. Both MSS and TM data over the Webster County, Iowa and Chicago, IL sites were received in "A" and "P" tape format. Radiometric and geometric evaluations were therefore possible for both data types over agricultural, urban, and water test sites. In addition, overall image quality and information content evaluations were carried out on Arkansas, Iowa, and Chicago data. The results are discussed briefly in the Results section. Detailed discussion of results will be made available through conference and journal papers.

Problems

The data received were in satisfactory form with regard to readability and format, except for Band 7 of the Iowa site. This band was missing from the CCTs received; this problem was communicated to Goddard and the scene was reordered. The reordered data were received and made available by February 14, 1983 so analysis of 7-band data from Iowa was not possible in the quarter. Six-band analysis was carried out, however.

Significant Results

The significant results for this quarter are contained in two papers to be presented at the Landsat-4 symposium on February 22-24, 1983. Also, results obtained from MSS evaluations were submitted on January 14, 1983 for use in the MSS evaluation documentation. Abstracts for the two papers and the short MSS report are attached as documentation for significant results in the quarter.

Key results items are that the MSS bands are registered to within approximately one-quarter pixel; however, it is not known what the specification is. If it is .3, then the MSS meets specifications. If it is .2, then the results are in conflict since the offsets are greater for the P tape than for the A tape. This result was questioned by Goddard and we checked the software and re-ran the analysis and came up with the same result. At this point, we cannot explain this difference. A second MSS result is that wavelike noise patterns exist in dark scene areas which suggest jitter effects. The amplitude is two to five count peak-to-peak variation with wavelengths from three to nine pixels, generally horizontally. More detailed results will be presented in subsequent reports.

TM results obtained in the quarter further verified the misregistration of the middle IR bands by .5 pixel and the thermal band by 3 to 4 pixels. Correlation results were unreliable for the thermal band due to its uniqueness relative to the others; it was visually evaluated using blink comparison of a large water-cooling pond for the Dresden and nuclear power plant at Joliet, IL. We determined that the thermal IR misregistration was four 30m pixels to the east and one 30m pixel south. This translational shift was subsequently removed from all TM data being used at LARS. Further TM results are discussed in the Appendix.

Publications

The only publication was the MSS report submitted to NASA/Goddard on January 14, 1983, which is included in the Appendix.

Recommendations

Correction of the thermal and middle IR band TM misregistrations is the primary recommendation. Noise artifacts in the MSS data have a significant amplitude relative to the dynamic range and should be evaluated with respect to data utility. Its presence with and without the TM operating should be evaluated.

Funds Expended

The funds expended on the project are reported periodically by the Purdue Office of Contract and Grant Business Affairs to the sponsor on NASA Form 533M. These are issued monthly. Specific disclosure of funds expended in this form of technical report is not permissible. If a quarterly summary is required, it can be prepared as a separate document by Purdue OCGBA.

Data Utility

Users should attempt to move the thermal IR band left four pixels and up one to make this band usable at least for TM data acquired through October 23, 1983. No other severe TM problems were observed which would affect data utility at this point. MSS noise problems should be documented although the effect on utility cannot be predicted.

APPENDIX

SPATIAL RESOLUTION ESTIMATION OF LANDSAT-4 TM and MSS DATA

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SUMMARY

In order to verify that the Landsat-4 sensors are operating within specifications, it is useful to estimate the system parameters by analysis of the measured data. One parameter of particular interest is the sensor point-spread function (PSF) which determines the resolution of the system.

A method of estimating the PSF has been developed that utilizes data obtained during scanning of ground elements having identifiable geometric and radiometric structure. These data are then processed in such a manner as to recover either the PSF itself or to estimate the parameters of an assumed functional representation of the PSF.

The measured data can be expressed in the spatial domain as a convolution of the scene with an overall point-spread function:

$$g(x,y) = h(x,y) * f(x,y)$$

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where $f(x,y)$ is the earth scene

$h(x,y)$ is the overall point-spread function of the sensor system

$g(x,y)$ is the resulting image

Given $g(x,y)$, we wish to determine $h(x,y)$ or its Fourier transform $H(u,v)$. To do this, some deterministic element of the input $f(x,y)$ must be known or assumed. Although the theory takes into account the two-dimensional nature of the element, the initial experiments have been limited to the one-dimensional case. Three useful elements of this type are:

1. A step function represented by an abrupt change in gray level along a row or column of the data.

2. An impulse represented by a narrow-width discontinuity along a row or column of the data.

3. A rectangular pulse represented by a sequence of two steps in opposite directions along a row or column of the data.

The point-spread function estimation method described in the paper uses horizontal and vertical roads in Landsat-4 MSS and TM images. The two-dimensional function is solved as two one-dimensional functions under the assumption that the PSF is separable; i.e.,

$$h(x,y) = h_x(x)\ h_y(y)$$

The steps in carrying out the solution are:

1. Each scan line across a road is modeled as an ideal point response

$$f_i p_i = p_i\ \delta(x-x_i)$$

p_i = magnitude of the ideal point source

x_i = location of the point source

2. Each point response is adjusted such that the locations of the point sources align with each other and an average point response is computed.

$$g_i(x) = p_i \, \delta(x-x_i) * h(x) = p_i \, h(x-x_i)$$

$$\bar{g}(x) = \frac{1}{M} \sum_{i=1}^{M} g_i(x+x_i) = \frac{1}{M} \sum_{i=1}^{M} p_i h(x) = [\frac{1}{M} \sum_{i=1}^{M} p_i] \, h(x)$$

Therefore:

$$h(x) = K \, \bar{g}(x)$$

where $K = 1/[\frac{1}{M} \sum_{i=1}^{M} P_i]$

Once an estimate for the PSF has been obtained to within an (unknown) constant factor K, a quantification of the width of the function can be made. Three methods are of general interest and are defined in one dimension, as follows:

1. Half amplitude width $W_{\frac{1}{2}}$ = width at which the magnitude of h(x) falls to one-half of its value at the origin.

2. Equivalent width $W_e = \dfrac{\int_{-\infty}^{\infty} h(x) \, dx}{h_{max}}$

3. rms width $W_{rms} = 2 \, r$

$$r^2 = \frac{\int_{-\infty}^{\infty} x^2 \, h(x) \, dx}{\int_{-\infty}^{\infty} h(x) \, dx}$$

Similar quantitites can be defined to estimate the bandwidth of the modulation transfer function (MTF) and are represented by $B_{\frac{1}{2}}$, B_e, and B_{rms}. The method was applied to Landsat-4 MSS and TM images from the Webster County, Iowa area and the Chicago, IL area using interstate highways and major roads as test inputs. The results for these tests are obtained in the form of both spatial widths of the estimated PSF in pixels and the bandwidth of the modulation transfer function in cycles per pixel and by plots of the estimated PSF and MTF.

One result using 50 scan lines across a north-south road in Webster County, Iowa (TM data) is shown in Figure 1. The PSF width results are listed below:

Vertical road in Webster Co., Iowa area:

$$W_{\frac{1}{2}} = 2.0$$

$$W_e = 3.58$$

$$W_{rms} = 5.23$$

Evaluation of the method using an assumed step response will also be presented, along with results from the MSS and using data both from Iowa and the Chicago areas.

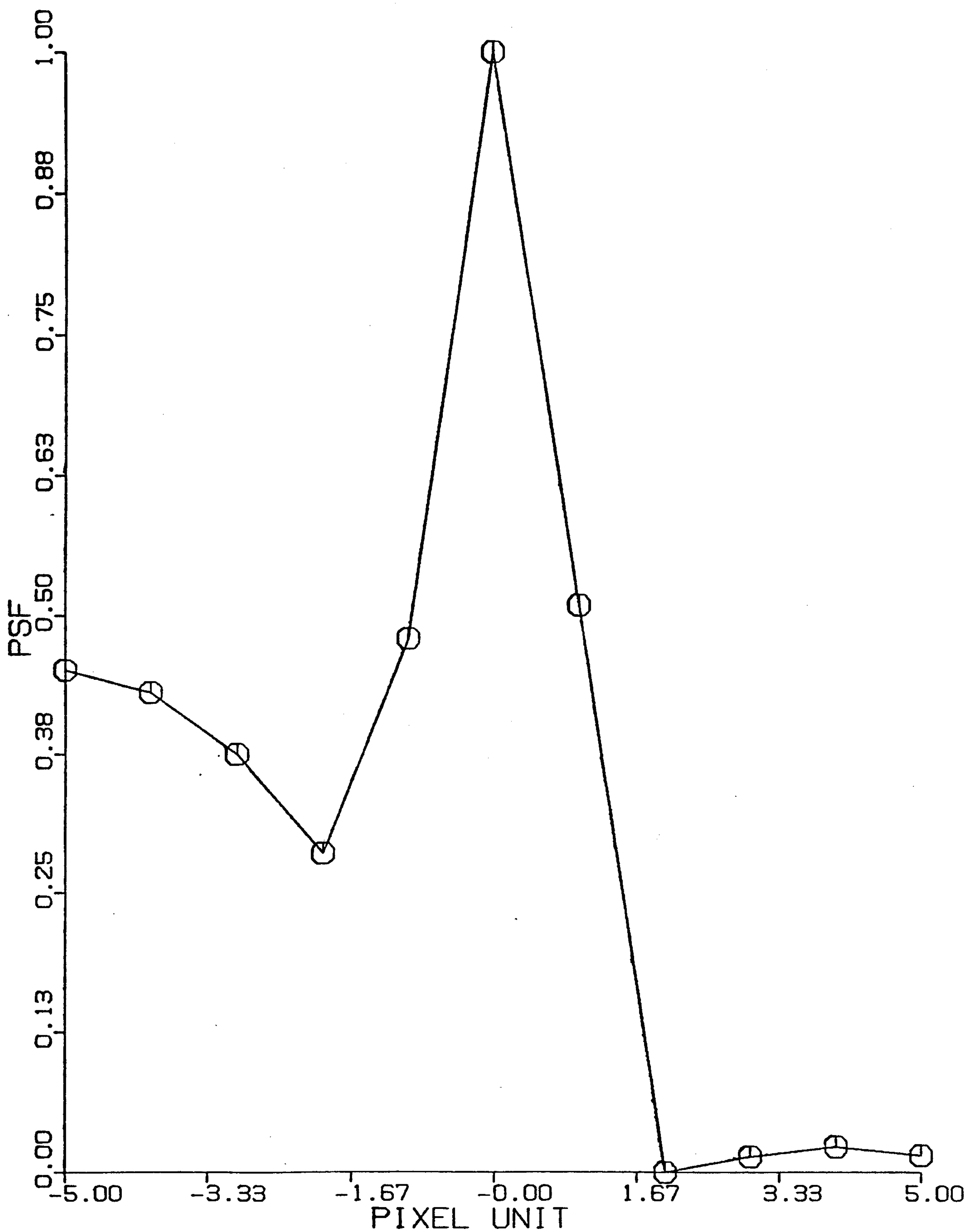

Figure 1. PSF using 50 location-adjusted scan lines.

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Landsat-4 Image Data Quality Analysis

NASA Contract NAS5-26859

MSS Data Quality Analysis Results

From

Laboratory for Applications of Remote Sensing

Purdue University

January 14, 1983

Introduction

MSS data from the Landsat-4 satellite is to be analyzed under this contract. Test MSS data were received late in December 1982 and early in January 1983 preventing analysis on the desired time schedule. Quick-look analysis was performed as soon as possible in consideration of a January 18, 1983 deadline for submission of results.

Included in this report are geometric and radiometric tests performed on MSS data from our Iowa and Chicago test sites.

Geometric Analysis

Band-to-band registration of the four MSS bands was evaluated using a line correlation algorithm, as was discussed in conjunction with TM analysis in previous reports. The results are presented in Table 1.

The largest indicated shift is .27 pixel; it can be considered satisfactory relative to a .2 pixel requirement. The imagery was visually inspected and found to be relatively free from artifacts in terms of block shifts, line shifts, and spots as had been seen in early TM data.

Table 1. Results of Band-to-Band Registration Analysis of Webster Co., Iowa Data

A Tape Correlations
Band

Band	2	3	4
1	.19	.06	0.0
2		-.10	.09
3			.15

P Tape Correlations
Band

Band	2	3	4
1	.27	.06	.21
2		.01	.26
3			.22

Bands 1 and 2 had low signal-to-noise ratio and Bands 3 and 4 were of high visual quality for land areas. A lateral displacement pattern of 12 lines was observed in the A data for September 3 which was mostly removed from the P data. This was not official release data as it was before the September 15 EDC cutoff (or turn on) date. The October 23 Chicago data were of high quality, but some lateral shifting of roads on a 6-line interval was observed.

MSS data over Lake Michigan showed significant noise patterns which we believe are due to jitter. Wave-like patterns run top to bottom and are spaced 14 to 15 columns between peaks in the P data. A high-frequency wave of 3 samples may be superimposed on these waves. The pattern oscillates down the scene with a period of 67 lines on the A tape, indicating a low-frequency component. The lower half of the Chicago scene also contains a 9-line horizontal striping on the P tape. The consequence of these artifacts cannot be predicted at this time. The amplitude of the striping artificats in the lake was investigated and example patterns through the waves in count observed are: Band 1 horizontally: 15 14 14 15 14 14 15 13 14 15 15 12 14, indicating a peak-to-peak variation of four counts. A typical Band 2 sequence is 6 6 7 7 6 6 9 6 6 7 7 4 6 6 which is a five-count max variation.

Band 4 had a sequence of 2 2 2 2 2 0 2 2 2 2 with the twos very random, but the wave pattern was the same as in Band 1,2,3. The conclusion is that if this is jitter, the peak-to-peak amplitude is two to four or five counts.

Radiometric Analysis

Detector-to-detector calibration was evaluated by computing means and standard deviations for the six detectors of each band. These results are presented in Tables 2 and 3 for the A tapes for the Iowa and Chicago test sites. The maximum deviations in mean and standard deviation for the two sites and four bands are given in Table 4 below.

Table 4. Maximum Deviations of Mean and Variance of Any Detector for MSS Bands.

	WEBSTER CO. A Data		CHICAGO A Data	
Band	Mean	Std. Dev.	M	σ
1	-.28	.43	.2	.16
2	.30	-.28	.2	.25
3	.82	.29	.13	.23
4	.44	.2	.11	-.12

The maximum deviation in any case is .82 in mean and .43 in σ and this is for September 3 data. The Chicago data are even more uniform. These results indicate very little striping exists in MSS data delivered after the release date.

Table 2. Deviations of Mean and Standard Deviation of MSS "A" Data from Webster Co., Iowa, Sept. 3, 1982

	BAND 1		BAND 2		BAND 3		BAND 4	
	Grand Mean 18.4	Grand Std. 3.04	Grand Mean 12.44	Grand Std. 4.0	Grand Mean 60.64	Grand Std. 13.08	Grand Mean 27.82	Grand Std. 6.5
Detector	Deviation	Deviation	Mean Deviation	Std. Dev. Deviation	Mean Deviation	Std. Dev. Deviation	Mean Deviation	Std. Dev. Deviation
1	.21	.43	.30	.24	.33	-.21	-.06	-.11
2	.15	.42	.11	.36	-.16	-.01	-.11	-.02
3	-.13	-.06	.14	-.13	-.23	.29	-.07	.20
4	-.28	-.37	-.09	-.28	-.50	-.25	-.15	-.01
5	-.03	-.13	-.17	-.11	-.29	-.03	-.07	-.11
6	.05	-.31	-.29	-.1	.82	.18	.44	.06

Table 3. Deviation of Mean and Standard Deviation for MSS "A" Data From Chicago Site, Oct. 23, 1982

	BAND 1		BAND 2		BAND 3		BAND 4	
	Grand Mean 21.38	Grand Std. 4.2	Grand Mean 18.81	Grand Std. 5.47	Grand Mean 31.2	Grand Std. 5.38	Grand Mean 25.26	Grand Std. 4.53
Detector	M. Dev.	σ Dev.	M Dev.	σ Dev.	M Dev.	σ Dev.	M Dev.	σ Dev.
1	-.07	-.14	-.14	-.21	-.10	-.18	-.09	.01
2	-.06	.03	-.03	.03	.07	.23	.08	.25
3	-.03	.16	-.04	.25	.13	.16	.11	.09
4	-.07	.03	-.05	.17	.02	.04	.06	-.1
5	.03	-.13	.06	-.16	-.12	-.07	-.11	-.12
6	.20	.02	.20	-.06	.01	-.21	-.08	-.12

Additional analysis was performed using clustering and separability measures. Vegetation, soil, and water classes were clustered in the A and P data and the divergence distances between these classes were computed. No significant differences were observed between the results, indicating no effect due to resampling and rescaling to 57-meter pixels.

A discrepancy was found in the stated data range for Band 4 of the MSS of 128. Data values for cloud response which should be at saturation were found to be 63 on the P tape and not 127. A very few counts were seen at the 127 level but not enough to be the cloud and were assumed to be noise.

Evaluation of the Radiometric Quality of the TM Data Using Clustering and Multispectral Distance Measures

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Introduction

The primary objective of this investigation was to evaluate the radiometric quality of the Thematic Mapper (TM) data for classification and identification of earth surface features. In addition, a comparison of the information content between TM and MSS data sets was carried out. Finally, the TM data were utilized to map the thermal effluent discharge into a river ecosystem from a nuclear power plant, an application only possible until now through the acquisition of thermal infrared scanner data from aircraft altitudes.

Procedures

Radiometrically corrected (A-tape) and geometrically corrected (P-tape) TM data from three different geographic locations were utilized in this investigation. A description of these data sets is given in Table 1.

Table 1. TM Data Sets

Scene ID	Date	Location
40037-16031	8/22/82	Arkansas
40049-16264	9/03/82	Iowa
40101-16025	10/25/82	Illinois

The initial examination of the TM data consisted of an inspection of the histograms for each band to determine the dynamic range of the data, the shape of the distributions, and to verify whether empty bins were introduced by the radiometric correction process.

In order to assess the effect of the geometric correction process (resampling effects) on the radiometry of the new resampled pixels, the means and variances for homogeneous and heterogeneous areas on the ground scene were calculated using both the A and P tape data sets. Furthermore, to determine the influence of resampling on the structure of the data, clustering of the A and P tape data sets of the same areas on the ground were performed. The resulting cluster classes from the original and resampled data sets were then compared using a transformed divergence measure. The results of this multispectral distance measure were also used as a feature selection criterion to obtain the optimum combinations of spectral bands for dimensionality reduction purposes.

The intrinsic dimensionality of the TM data was also studied by means of a principal components analysis. A Karhunen-Loeve transformation was applied to both the MSS A and P and to the TM P data tapes of the Chicago O'Hare airport test site. Statistics used to generate the transformation matrices for each of these data sets were calculated from samples of the data taken from every 5th line and 5th column in the scene. The resulting transformed components were scaled to be proportional to the square root of their respective eigenvalues, with the first component set equal to a range of 0-255.

In multidimensional space, such transformations will not alter the Euclidean distance between data points. However, if the resulting components are given some relative magnitude or length other than values which are proportional to the square roots of their respective eigenvalues, then the Euclidean distance between data points will be altered. Clustering algorithms are often highly sensitive to such movements or changes in position of data points with respect to each other. Therefore, it is important for clustering and classification purposes that the resulting transformed components of such orthogonal transformations be (each) correctly scaled.

To assess the utility of high (spatial) resolution thermal infrared data for thermal pollution studies, TM data over an area south of Chicago, Illinois, were classified using a layered classifier to first discriminate water from everything else with the aid of the reflective infrared bands, and then to perform a level slicing of the thermal band for only the resulting water pixels, thus producing a temperature map of the thermal plume. The linearity of the calibration of the thermal band was also studied for various temperature ranges.

Results

An evaluation of the histograms from the A and P tape TM data sets shows that the data in the three reflective infrared bands have a larger dynamic range than the data in the visible and thermal bands. It was also observed that the shape of the distributions in the three visible bands, especially in the blue band, deviated considerably from a normal curve, approximating a distribution highly skewed towards the higher response values. This phenomenon was not observed in the Landsat 4 MSS bands corresponding to the visible portion of the spectrum. This histogram also showed that the A tape data from both the MSS and TM systems contained a number of empty bins. As it would be expected, empty bins were not found in either the MSS or TM P tapes, since the gray level interpolation applied to the geometrically corrected data would eliminate such effects.

From past experience at LARS, there was concern about the magnitude of the radiometric changes that would occur on resampled (gray level interpolated) pixels. To determine quantitatively the effect of the interpolation, individual pixels and sets of pixels representing the same features on the ground were examined. The results indicate that the interpolation did not affect the means and variances of the spectral response of ground cover types. In fact, the smoothing effect that the cubic convolution was expected to have on the radiometry of the data was not evident in these results as illustrated in Table 2.

In order to further evaluate the effects of the cubic convolution on the structure of the geometrically corrected TM data, the same areas on the

Table 2. Means and Standard Deviations for Homogeneous and Heterogeneous Areas in the TM A and P Data Sets.

Bright Homogeneous Target

	Spectral Band	1	2	3	4	5	6	7
TM A-tape	Mean	72.64	33.75	37.93	64.59	119.95	57.23	136.77
	Standard Deviation	2.27	1.45	2.85	2.49	6.37	3.28	3.74
	Spectral Band	1	2	3	4	5	6	7
TM P-tape	Mean	72.88	33.95	38.30	64.34	120.80		137.75
	Standard Deviation	2.18	1.42	2.83	2.52	6.54		3.46

Heterogeneous Area

	Spectral Band	1	2	3	4	5	6	7
TM A-tape	Mean	68.31	29.56	26.94	89.58	75.75	27.94	127.78
	Standard Deviation	15.31	8.91	13.12	21.30	16.35	12.62	4.53
	Spectral Band	1	2	3	4	5	6	7
TM P-tape	Mean	68.28	29.56	26.90	89.77	75.92		127.83
	Standard Deviation	15.36	8.94	13.10	21.80	16.42		4.65

ground were selected in the A and P TM images and both data sets were clustered. The statistical parameters (means and covariance matrices) that describe the resulting cluster classes from both the A and P TM data sets were found to be virtually identical; but to determine more quantitatively the similarity between corresponding class pairs, a Transformed Divergence (Spectral Separability) algorithm was used. Table 3 illustrates the results of this separability analysis. The Transformed Divergence values range from zero (identical spectral classes) to 2000 (completely different spectral classes).

The same spectral separability measure was also used as a feature selection function in order to determine the best combination (subset) of bands that would provide the most accurate multispectral classification results. Also, the MSS data for the same areas on the scene were clustered and the results were compared with the resulting cluster classes from the TM data in an attempt to learn more about the information content from the two multispectral scanner systems.

Finally, a temperature map of a nuclear power plant cooling pond and the thermal plume discharged into the Illinois river was produced using a Layered Classifier and calibrating the relative digital counts in the thermal IR band into degrees Celcius. It will also be shown that the relationship between the thermal IR radiation and the corresponding radiant temperature is not a linear function for the 10.4-12.5 μm band and for the range of temperatures from 260K to 320K.

Table 3. Separability for the Merged A and P Tape Cluster Classes.

Classes Considered

	Symbol	Class
A Tape	A	TM- 1/16
	B	TM- 2/16
	C	TM- 3/16
	D	TM- 4/16
	E	TM- 5/16
	F	TM- 6/16
	G	TM- 7/16
	H	TM- 8/16
	I	TM- 9/16
	J	TM-10/16
	K	TM-11/16
	L	TM-12/16
	M	TM-13/16
	N	TM-14/16
	O	TM-15/16
	P	TM-16/16
P Tape	Q	TM- 1/16
	R	TM- 2/16
	S	TM- 3/16
	T	TM- 4/16
	U	TM- 5/16
	V	TM- 6/16
	W	TM- 7/16
	X	TM- 8/16
	Y	TM- 9/16
	Z	TM-10/16
	$	TM-11/16
	+	TM-12/16
	=	TM-13/16
	/	TM-14/16
	A	TM-15/16
	B	TM-16/16

Class Pairs	D_T (Combination of all bands)
AQ	59.
BR	53.
CS	164.
DT	85.
EV	35.
FU	150.
GW	60.
HX	99.
IY	108.
JZ	262.
K$	63.
L+	62.
M=	22.
N/	37.
OA	168.
PB	75.