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NAS9-14970
T-1314/4
MA-129TA

CR151452
E77-10185

Final Technical Report

NASA Contract NAS9-14970

June 1, 1976 - May 31, 1977

(E77-10185) [APPLICATIONS OF REMOTE SENSING, VOLUME 3] Final Technical Report, 1 Jun. 1976 - 31 May 1977 (Purdue Univ.) 78 p HC A05/MF A01 CSCL 05B

N77-30549

Unclas
G3/43 00185

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Volume III of III

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The Laboratory for Applications of Remote Sensing
Purdue University West Lafayette, Indiana

1977

Table of Contents

RESEARCH TASKS

Volume III reports on tasks which are to be continued. Therefore, only a progress report for the fourth quarter is provided. Exceptions to this are tasks 2.8 and 2.12 which were terminated some months ago. A brief summary of the work under these tasks is provided here for completeness.

2.3 Field Measurements for Remote Sensing of Wheat

Field Measurements activities during this quarter have included: project leadership and coordination, data processing and evaluation, data library management, data analysis, and preparation for summer data collection at Williston, North Dakota.

Project Leadership and Coordination

Early in the quarter three sets of examples of field measurements data were prepared. Examples of each of the primary data types were included, with emphasis on the data from the helicopter and truck spectrometer systems. Two of the notebooks were forwarded to NASA/JSC for NASA Headquarters and NASA/JSC. On May 5 a presentation describing the project with illustrations of typical data, particularly spectrometer data, was made at the LACIE Project Monthly Review Meeting.

A plan and procedures for the sensor comparison experiments to be performed in Finney County, Kansas during mid-May were prepared and sent to NASA/JSC for review and comments. Inputs have been received from NASA/JSC that make the procedures more compatible for the instrument systems involved. The systems involved are the NASA/JSC FSS and FSAS spectrometer systems and the Purdue/Lars Exotech 20C spectrometer system. The purpose of the sensor comparison experiments is to determine how well the output of the systems correlate.

Data Processing

During this quarter significant progress was made in completing the processing of the 1975-76 Field Measurements Project data. The 1974-75 data processing was completed the previous quarter. Processing of the fall 1976 data is currently underway. The status of the data is summarized in Tables 2.3-1.

FSS Data. The 1975-76 FSS data (both field averaged and single scan formats) were calibrated using the calibration panel spectral reflectance measurements determined by the truck-mounted spectrometers for the summer. An evaluation of the 1976 FSS spectral reflectance calibration tables and the 1975 FSS calibration tables prepared last fall indicated that the calibration of the 1975 FSS data could be improved upon. The 1975 FSS data were therefore recalibrated using updated tables. The change in the calibration of the 1975 data does not affect the relative comparison of spectra collected on a given data. The change, however, will affect relative comparisons from date to date in some cases.

The processing of the fall 1976 data began during this quarter. These initial steps include key punching the ground observations.

LARS Spectroradiometer Data. Processing of the Exotech 20C data collected at the Williston Agriculture Experiment Station during the summer of 1976 was completed. A review of the data indicated that a few runs were of questionable quality and need to be reprocessed. The data will be distributed when the reprocessing of the questionable runs is completed. Processing of the Exotech 20C data collected in the "modeling field" is one-third completed.

During this quarter several ways to reduce the amount of time required to process the Exotech 20C data were examined. Some of the possible ways include an onboard digitizer in the truck, minicomputer processing, and better procedures for handling the bookkeeping and ground observation data. At present the cost of the digitizer and minicomputer systems are restrictive; more evaluation is needed to determine the cost/benefits of the systems. New procedures for handling the bookkeeping data and ground observations are being implemented this summer.

JSC FSAS Data. All of the spring-summer 1976 FSAS data has been received and processed. A review of the post-calibration of the FSAS field standard indicated that the calibration table for the 1976 FSAS field standard could be improved upon in the 2.1 to 2.4 μm range. Therefore, that data is currently being recalibrated.

Data Library

The 1976 FSS field average and single scan format data were distributed to researchers at the Environmental Research Institute of Michigan and Texas A&M University along with the recalibrated 1975 FSS data. A report discussing the FSS calibration was distributed with the data. Also distributed to ERIM and Texas A&M were the 1975-76 crop year set of ASCS periodic observations and ground truth inventories for the three test sites. Updating of Volumes 2 and 3 of the Field Measurements Data Catalogs for the 1975-76 and 1976-77 crop years is in process to reflect the current status of the data.

Data Analysis

Analysis of the truck-mounted spectrometer data from the Garden City, Kansas and Williston, North Dakota Experiment Stations is well underway with data acquired in 1975 and has begun for 1976 data. Analysis of variance and covariance analysis are being used as tools to investigate treatment differences, evaluate crop separability, and compare the discriminability capabilities of the Landsat and proposed thematic mapper bands. Currently, an analysis is being carried out to quantify the change in reflectance of measurements taken at different times during the day; data acquired over a sample of test plots at the Williston, North Dakota site on July 16, 1976 is being used for this evaluation which is vital for the optimum design of the 1977 data acquisition.

Graphs of the S-191 data from both the Finney County, Kansas and Williams County, South Dakota intensive test sites for 1975 have been examined to assess crop discriminability and changes in the spectral response of a crop over the growing season; statistical analyses will be performed to quantify these results. Single scan data are being analyzed to evaluate within field variability and compare it to between field and between crop variability. The same analysis tasks will be continued in the next quarter as well as regression analyses to correlate spectral and agronomic measurements.

In addition, the analysis of data set acquired over the modeling field at Williston, North Dakota on July 20, 1975 has been completed this quarter. The data set consists of spectral measurements over the range of 0.4 to 2.5 micrometers made at approximately half-hour intervals at five zenith and eight azimuth angles. A separate report of the results of this investigation is currently being prepared.

Preparation for Williston, N. Dakota Data Collection

Experiments were outlined and plans for data collection were developed in preparation for this summers data collection activities in Williston, N. Dakota. The experiments include a continuation of spring wheat and small grain treatment plots and the modeling field activities. The past two years experience and analysis of the data indicated that a change in the plot layout would improve the experimental design. The improved design is being implemented for this summer.

Also, during this quarter the Exotech 20C instrument was thoroughly tested. A new circular-variable filterwheel was installed for the silicon detector.

Table 2.3-1. Data Processing/Reformatting Status.

Instrument/Data Type	1974-75 Data	1975-76 Data			1976-77 Data		
	Completed & In Library	Completed & In Library	In Processing	At JSC	Completed & In Library	In Processing	At JSC
Landsat MSS							
Whole Frame CCT (Frames)	20 Frames	61	0	N.A.	14	0	N.A.
Aircraft Scanner (Dates/Runs)	19/149	16/97	0	1	~~6 2/10~~ 6/32	~~[illegible]~~ 0	2/
Helicopter Mounted Field Spectrometer (Dates/Runs)							
Field Averages	19/~~2,251~~ 2,343	27/2,193	0		0	8/41	1/
Individual Scans	19/~~35,000~~ 29,579	27/~~40,000~~ 38,476	0		0	8/41	1/
Truck Mounted Field Spectrometer (Dates/Runs)							
FSAS	6/65	23/322	0		0	1/2	2/
Exotech 20C	24/1,577	14/1,307	5/1,361		-	-	-
Exotech 20D	45/645	-	-		-	-	-

2.4 Scanner System Parameter Study

Background

The scanner parameter study was initiated in CY76 to conduct research on analytical methods of multispectral sensor system design. It was planned that basic information theoretic approaches would be taken to determine optimum performance levels achievable in a given environment against which to test performance of actual or modeled systems. Scanner system modeling techniques were to be developed which would permit explicit evaluation of scanner performance without the use of simulation techniques. The study includes representation of the scene and information extraction process to provide models of the environment in which the scanner would operate. Thus three main activity areas were defined (scene, scanner, and information extraction modeling) and research was begun in CY76

Shortly into CY76, the direction of the study was changed on request of the sponsor. A conventional simulation study of certain proposed thematic mapper parameters was requested using NASA 24 channel scanner data as input. This activity required almost all the project resources through the end of CY76 and the results were reported in the June 1976 final report and in LARS Information Note 110976 included as an appendix in this report. Research on the analytical model program was resumed in CY77. Progress has been made in the three basic areas defined for the study. The work is reported with respect to the appropriate tasks in the following sections.

Task 2: Spectral Data Base Development

The activities included in this task relate to the acquisition, reformatting preprocessing, error checking cataloguing and averaging of field spectrometer data for use in defining scene models. A large enough number of field spectra had been processed by the end of the third quarter to adequately support the planned research. The task was thus terminated at the end of the third quarter and was reported on at that time.

Task 3: Statistical Model Definition

The statistical modeling tasks have evolved as part of Tasks 4 and 7 and are reported as part of those tasks. This modification in task definition was discussed at the end of the third quarter and Task 3 was thus defined as completed at that time.

Task 4: Optimum Basis Function Study

The selection of wavelength band sampling functions to maximize the performance of a scanner system for classifying certain scene classes is subject of this task. The wavelength sampling functions are being called the basis functions here since the approach being taken is to represent the spectral response from the scene by a finite weighted sum of functions which are derived from the statistics of the spectra themselves. Two approaches are being pursued. The first is based on the use of the Karhunen-Loeve (K-L) representation and the other is an information theory approach which utilizes the concept of mutual information. Both approaches have been discussed in detail in previous reports. A summary of progress on the two approaches in the fourth quarter is presented below:

K-L Representation Approach. As a step toward the goal of analytically designing an optimum remote sensing system, the efforts this quarter have been directed towards developing an upper bound on the performance capability of such a system to discriminate between two classes. Such performance bounds will provide guidelines for designing practical systems.

A preliminary method has been developed to estimate the performance bound for some representative field data. The method can be broken down into four steps: 1) estimation of the parameters of the process; 2) a "whitening" transformation; 3) computation of the likelihood ratio; and 4) computation of a bound on the performance.

The estimation of parameters involves finding the maximum likelihood estimates of the mean and covariance matrices for each class. The random process consists of an ensemble of functions of wavelength, and the statistics of the process are assumed to be Gaussian. The members of this ensemble and their associated probabilities of occurrence are assumed to be given for the particular remote sensing problem.

To simplify the computation of the likelihood ratio and the performance bound, one class is "whitened" with respect to the other class. This is done such that the transformed covariance matrix for one class is diagonal and for the other class the covariance matrix is the identity matrix.

The optimum classifier is derived from the expression for the likelihood ratio. The likelihood is defined as the ratio of the probability density functions of the two classes [1]. Classification can be performed by computing this ratio for each sample function, comparing the computed value with a threshold, and deciding in favor of a class depending on whether the ratio was greater than or less than the threshold.

A bound on the performance is obtained by computing the Bhattacharyya distance between the classes [1]. The method described above makes the computation of this distance particularly simple. The bound on the probability of error is exponentially related to the Bhattacharyya distance.

An experimental software system has been set up to implement the four steps of the method and estimate the capability of the system to discriminate between any two classes. A trial experiment using wheat and fallow data is being used as a design and test mechanism. Approximately thirty sample functions from each of the classes were taken from S191 helicopter data over North Dakota. Each sample function consists of twenty bands over the interval 0.4 to 2.4 micrometers. Use is made of the Karhunen-Loeve expansion to generate the transformation vectors for the whitening transformation.

In the coming quarter work will continue to further refine the optimum system and compare it with practical systems.

Reference:

[1] Van Trees, H.L. (1968), Detection, Estimation and Modulation Theory, Part I, John Wiley and Sons, New York.

Information Theory Approach. The approach taken to the spectral basis function selection problem is to model the spectral response as a portion of a sample function from a stochastic process in wavelength (see previous quarterly reports). It can be shown that between any two spectral wavelengths λ_1 and λ_2 the information is given by:

$$I(\lambda_1,\lambda_2) = \tfrac{1}{2} \int_{\lambda_1}^{\lambda_2} h(\lambda,\lambda)d\lambda$$

where $h(\lambda,\lambda)$ is the optimal Weiner filter for estimating the spectral response of the actual scene from the observed spectral process. Evaluation of $h(\lambda,\lambda)$ requires the construction of an adequate model for the spectral process of a scene.

It was decided to model the scene in a manner such that Kalman filtering techniques may be used in the determination of $h(\lambda,\lambda)$ and hence the information in a spectral band.

Several classes of models were hypothesized and several models in each class were identified. The identification techniques used were based on maximum likelihood identification principles. Of the different classes of models considered, the integrated autoregressive models proved to be the most promising.

The best model in the class of integrated autoregressive models was found to be:

$$\nabla y(k) = \alpha_1 \nabla yk(k-1) + \alpha_2 \nabla y(k-2) + \alpha_7 \nabla y(k-7) + w(k)$$

where

$$\nabla y(k) \triangleq y(k) - y(k-1)$$

$y(k)$ = spectral response of the scene at wavelength k.

$w(k)$ = independent, identically distributed Gaussian random variables with zero mean and variance p.

Further $w(k)$ and $y(k-j)$ are assumed independent for all $j \geq 1$.

Several tests were conducted to compare the model to empirical data. These tests were used as a validation procedure for the model. Tests performed to validate the assumptions above were:

1. zero mean test

2. test for statistical independence
3. test for absence of sinusoidal components

Some simulation tests were performed to compare the statistical characteristics of the model and the empirical data. These tests considered:

1. correlation similarity
2. spectral similarity.

The above model seems to pass the validation tests and hence may be considered a model for the spectral process.

The next step is to put the above model into a form that is amenable to Kalman procedures for the determination of $h(\lambda,\lambda)$. Evaluation of the information then will follow. It is these tasks that will be addressed in the next quarter.

Task 6: Develop Numerical Methods Classification Error Prediction

In the previous quarters, an algorithm was developed for estimating the overall probability of misclassification (PMC) using numerical integration technique and requiring the mean and covariance matrices of different classes. Then the method was applied to the multispectral aircraft dater and results compared with the thematic mapper simulation experiment. These results were reported in the third quarter report. During the fourth quarter the scanner modeling effort (Task 7) was pursued and further work on Task 6 was delayed.

Tasks 8, 9: Implement Multispectral Scanner Model and Evaluate

The step that has been taken in the quarter is in the direction of formulating an input-output relationship for the multispectral scanner system. This approach would enable us to analyze the performance of the current system; moreover, once put in a proper mathematical/statistical model, the parameters of the system can be manipulated to optimize a given index of performance. Specifically, it is desired to obtain the PMC for a given set of classes once it has passed through the scanner. The comparison of classification accuracy at the input and output of the scanner reveals the degradation of the data quality due to additive noise and blurring properties of the scanner system.

Formulation of the problem:

The scanner is characterized by a 2-dimensional shift-invariant point spread function. Independent random additive noise is added at the output. See Figure 2.4-1

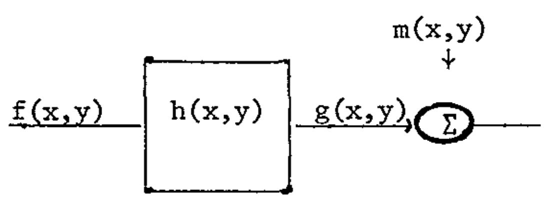


Figure 2.4-1. Scanner aperture model.

f(x,y) is a sample function drawn from a Gaussian, stationary random field with separable autocorrelation function.

Having the statistic of f(x,y) (i.e., mean and covariance matrix) there are at least two ways one can obtain the statistic of g(x,y): 1) Matrix operation; 2) spectral analysis.

1. A convolution in the discrete domain can be carried out using matrix operations

$$\underline{G} = \underline{H}\,\underline{F}$$

where F is the input matrix, H is the "circulant" PSF matrix (i.e., each row is the cyclic shift of the previous row), and G is the output matrix.

The main drawback here is the sheer size of the matrix involved. The mean of G is an NXN matrix and its covariance contains $N^2 \times N^2$ elements. Even for a modest size like N = 10, the covariance matrix will contain 10,000 elements. Moreover most of the information contained in these matrices is not utilized as long as the stationarity and ergodicity assumptions are invoked. For example, a scalar would be a valid and sufficient quantity for the mean of the process under those assumptions.

2. Co- and Cross-spectral analysis: Here using the established techniques we represent the statistics of the output process in an algebraic form such that parameter manipulation is considerably simplified. We attempt to obtain the autocovariance of the output process, because from the standpoint of practical applications, covariance and spectral characteristics can be conveniently used to get the statistics of the output of a linear shift-

invariant system operating in a stationary random environment. Let

$$h(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} e^{-(\frac{x^2}{2\sigma_x{}^2} + \frac{y^2}{2\sigma_y{}^2})}$$

$$R_f(\alpha,\beta) = e^{-a\frac{|\alpha|}{\sigma_x}} e^{-b\frac{|\beta|}{\sigma_y}} \quad \text{normalize variance} = 1$$

where $h(x,y)$ and $R_f(\alpha,\beta)$ are the scanner PSF and input autocorrelation function respectively. Now, it is well known that

$$S_g(u,v) = |H(u,v)|^2 S_f(u,v)$$

$$= M(u,v)S_f(u,v)$$

thus

$$R_g(\alpha,\beta) = R_f(\alpha,\beta)*m(\alpha,\beta)$$

$$= \iint R_f(\alpha-x,\beta-y)m(x,y)\,dx\,dy$$

Carrying out this integration, using the separability of h and R, the output sample-to-sample autocorrelation function will be

$$R_y(\alpha) = e^{a^2-a\frac{|\alpha|}{\sigma_x}} Q(\sqrt{2}\,a - \frac{a}{\sqrt{2}} \frac{|\alpha|}{\sigma_x}) + e^{a^2+a\frac{|\alpha|}{\sigma_x}} Q(\sqrt{2}\,a + \frac{a}{\sqrt{2}} \frac{|\alpha|}{\sigma_x})$$

where $Q(x)$ is the area under normal density function in the (x,∞) domain.

$R_g(\beta)$ is exactly the same with α, a and σ_x replaced by β, b and σ_y, respectively.

It should be mentioned that the entire entry of the aforementioned covariance matrices can be obtained using this expression but new random access to its elements is more convenient. In fact, at LARS, the value of interest is the autocovariance at zero lag, i.e., $R_g(0,0)$.

Cross-spectral correlation can be similarly computed but the quantity required is the cross correlation at the input. Therefore to obtain the output statistics, it is essential that a model for the auto- and cross-correlation functions be determined.

Experimental results:

Experimental results at this stage, due to data availability, is limited. The parameters to be determined are a and b in the autocorrelation function expression. The following method is employed: a preferably large field of a particular cover type is selected and the mean-lagged product is calculated for both horizontal and vertical directions. The maximum lag is chosen to be about a quarter of number of samples in each direction. Then a straight line is fitted through the natural logarithm of the correlation function and the slope is determined using a generalized least-squares criterion. The value of this slope is the desired parameter. It should be mentioned that not all cover types exhibit a strictly exponential correlation function and deviation from this shape is observed across the fields.

For illustration purposes we show an application of the above method to a sample field of harvested wheat from the 30-meter simulated thematic mapper data.

Field identification:

Run No.	Cover Type	Lines	Columns	#Points
75001730	Harvested Wheat	141-153	35-46	156

	a	b
ch 2	0.54	0.57
ch 6	0.54	0.57
ch 8	0.72	0.38

	a	b
ch 2,6	0.47	0.77
ch 2,8	0.3	+1.24
ch 6,8	0.45	+1.00

Exponential Model Parameters for
Auto- and Cross-Correlation Functions

	$\bar{e}^2$
ch 2	$1.82 \times 10^{-3}/2.06 \times 10^{-3}$
ch 6	$1.48 \times 10^{-3}/2.18 \times 10^{-5}$
ch 8	$1.76 \times 10^{-4}/4.23 \times 10^{-4}$

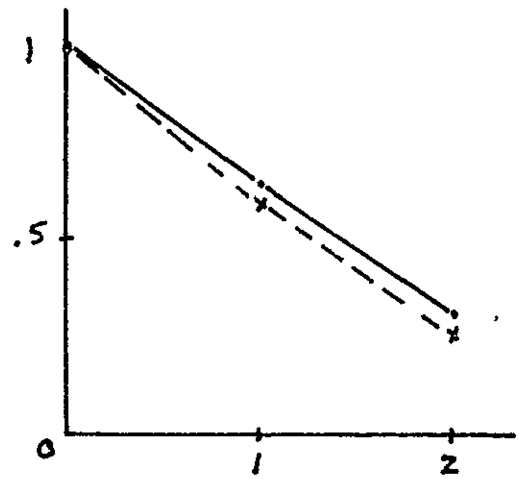
	$\bar{e}^2$
ch 2,6	$3.19 \times 10^{-3}/2.80 \times 10^{-3}$
ch 2,8	$1.08 \times 10^{-5}/3.64 \times 10^{-2}$
ch 6,8	$2.67 \times 10^{-4}/9.06 \times 10^{-2}$

Weighted Least Square Error for
Horizontal/Vertical Exponential Fitting

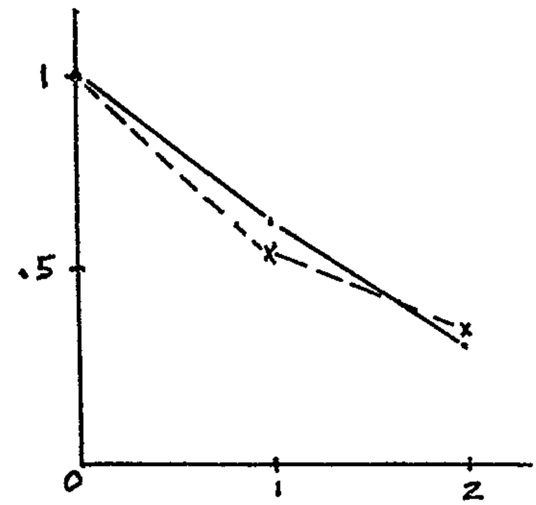
By looking at the plots in Figure 2.4-1 and 2.4-2 and weighted errors, it is observed that the correlation functions can be represented as decaying exponentials with generally good results, with some exceptions, e.g., line-to-line crosscorrelation between channels 6 and 8. Once the parameters in the correlation model are determined as shown above, output statistics for any cover type can be computed, with the accompanying classification accuracy.

The preceding results concerning a particular field of harvested wheat is obviously not meant to be a complete and exhaustive model for this cover type. This process must be repeated for each crop, encompassing many fields and at the end, generating a complete and comprehensive correlation model for each channel and across-spectral lands.

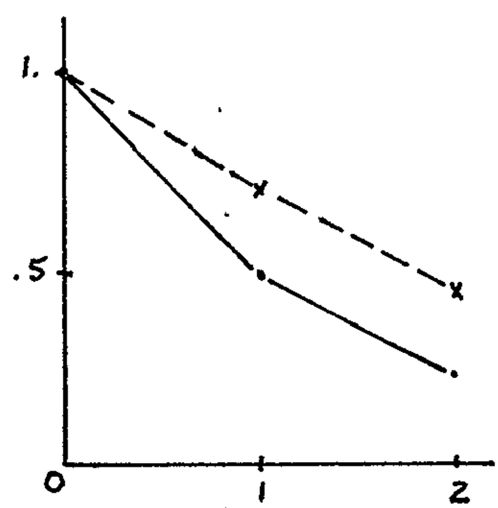
This completes the report of progress on the Scanner Parameter Project for the fourth quarter of CY77.



Channel 2.
Normalized to 40.22



Channel 6.
Normalized to 36.78

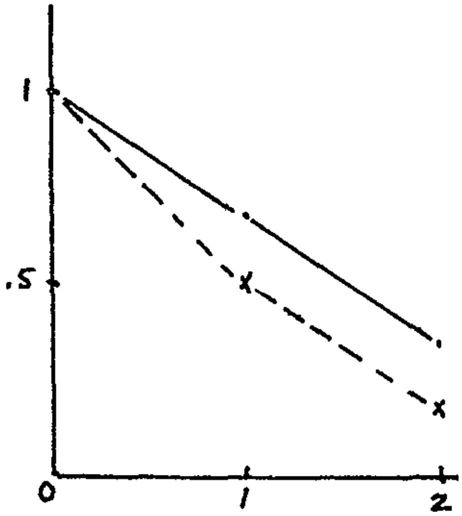


Channel 8
Normalized to 23.17

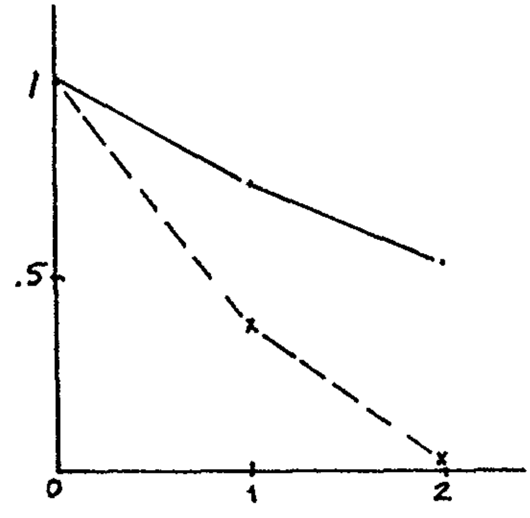
——— Sample-to-Sample Correlation

– – – – Line-to-Line Correlatio

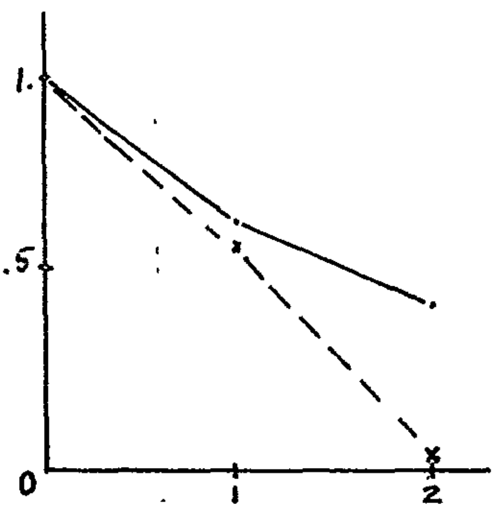
Figure 2.4-1. Normalized Autocorrelation Function versus Lag.



Channels 2 and 6.
Normalized to 33.72.



Channels 2 and 8.
Normalized to 13.7.



Channels 6 and 8.
Normalized to 12.37.

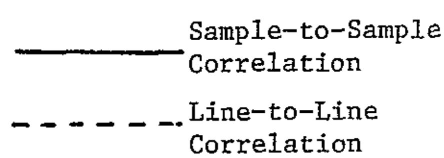


Figure 2.4-2. Normalized Crosscorrelation Function versus Lag.

2.5 Transfer of Computer Image Analysis Techniques

The successful transfer of computer analysis techniques from a research environment to an applications environment by means of a remote computer terminal requires a careful blending of hardware and software supported with adequate training materials and procedures (Figure 2.5-1). Since its installation in late 1972, the JSC/LARS remote terminal has incorporated these four components in its remote terminal operations. As the concept has grown and developed the relative emphasis in each of these areas has varied according to current needs and requirements. This is shown in Figure 2.5-2. This contract year has seen an increasing emphasis on upgrading the hardware capability of the JSC/LARS terminal as well as the development of training materials to test and evaluate new classification algorithms.

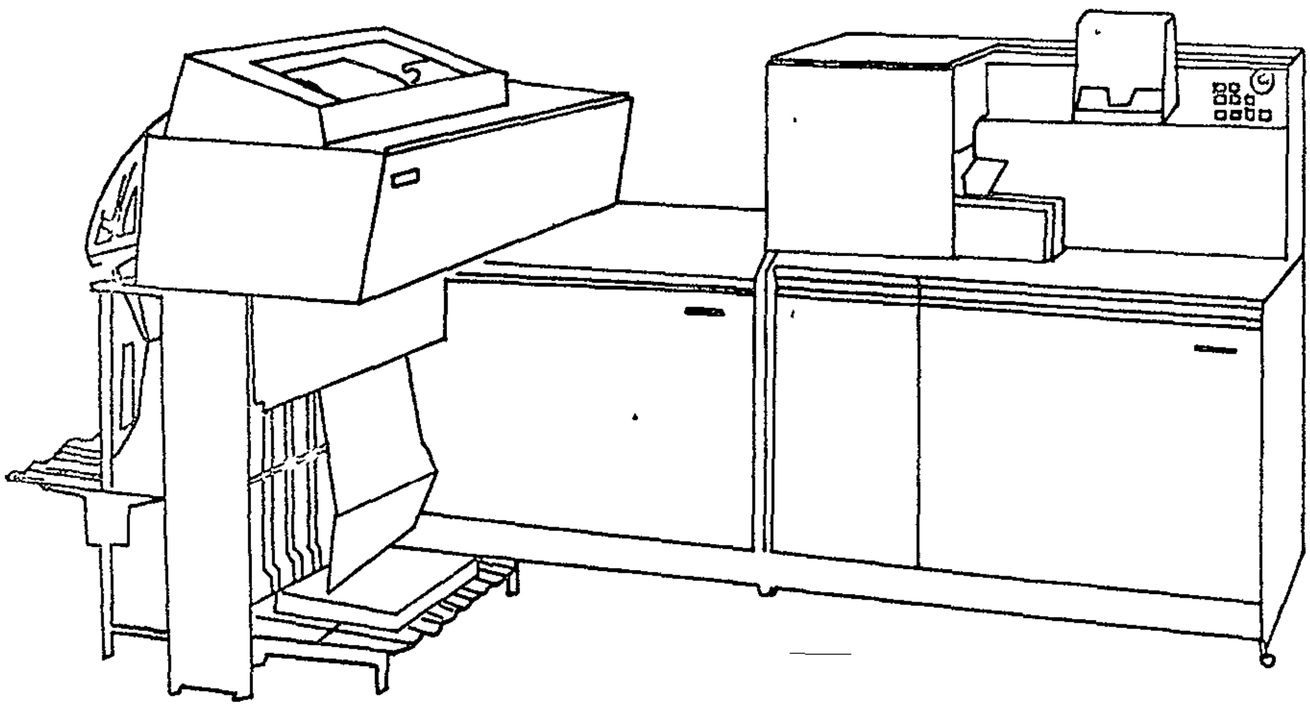
This section summarizes the major activities carried out under Task 2.5 with emphasis on accomplishments made during the period March 1, 1977 through May 31, 1977. The major activities were:

- Remote Terminal
  - 2780 Support
  - Data 100 Installation Plan
  - LITER Development
- Development of Education and Training Materials
  - ECHO Case Study

Progress in each of these areas are described in the paragraphs below. Following this is a proposed technology transfer milestone chart and a discussion of work planned for the future.

<u>2780 Support</u>. Support of the JSC/LARS 2780 remote terminal includes maintaining at the LARS computer facility the necessary hardware and software, providing computer services, providing hardware/software system consultation, and developing concepts for an improved remote terminal system.

REMOTE TERMINAL SYSTEM



- HARDWARE
- SOFTWARE
- TRAINING MATERIALS
- PROCEDURES

Figure 2.5-1

Year	Major Activities	Emphasis
1972	Installation of remote terminal	Hardware, training, procedures
1973	LARSYS 3.0 release, Revised training package	Software, training
1974	LACIE Analyst training	Training
1975	LARSYS 3.1 release, LANDSAT Case Study	Software, training
1976	Simulation exercises, training procedures documented	Training, procedures
1977	Terminal upgrade, ECHO Case Study	Hardware, new algorithm training

Figure 2.5-2 Historical picture of JSC/LARS remote terminal activities showing how relative emphasis shifts between hardware, software, training and procedures depending on current needs.

Hardware support consists of maintaining communication modems at LARS and a port on the 3705 communication system. Software support includes programming the 3705 to recognize the JSC terminal, CP-67 and LARSYS software, and maintaining a virtual machine dedicated to the JSC terminal.

During this period, communications with remote terminal users at JSC increased markedly. It was decided that certain routine requests, such as ID changes and data reformatting requests could go directly through Bob Peery or Jim Tyler at JSC, with copies of information sent to John Sargent. A current list of computer IDs and passwords was mailed to Jim Tyler, and several computer IDs have received increased disk storage space during this quarter. In April, a memorandum discussing the scheduled Labor Day installation of an IBM 370/148 computer here at LARS was sent to all remote terminal sites. The effect of this change on remote terminal users, aside from a few days of down time, should be minimal. No hardware changes are required and user interaction with the system will remain almost the same as now. In addition, the remote sites will gain the capability to manipulate their printer output files.

At the request of a remote terminal user at JSC, PL/I was made available to JSC and has been successfully used. Also during this quarter a LARS update to the CP-67/CMS manual was mailed to all remote sites, and a copy of additional system information was sent to JSC at the request of a JSC terminal user. Two data runs were entered into the LARS data library during this period, although one data entry was delayed because one of the CCT's received by LARS was unreadable.

We have noticed that one or two JSC users are making frequent use of the dial-up lines into the Purdue/LARS computer. If this dial-up access is desired by JSC for the future, we recommend investigation of obtaining dial-up access to the Codex multiplexer at JSC which would then make use of the existing leased line between JSC and Purdue/LARS.

Computer usage for the period February, 1977 through April, 1977 was as follows:

Month	CPU hours used	Hrs. terminals attached
February	12.2 hours	291 hours
March	17.1 hours	378 hours
April	11.4 hours	289 hours

Data 100 Installation Plan. In response to NASA's request (December 20, 1976), LARS has estimated the performance, cost, and schedule for installation of a tape drive capability on the JSC/LARS terminal. During the December 1, 1976 to February 28, 1977 quarter three approaches were investigated. Their throughput capabilities, hardware cost and requirements, software requirements and leadtimes were presented in the December 1, 1976 - February 28, 1977 quarterly report. Subsequent to the writing of that report a fourth option utilizing a Data 100 terminal became feasible. This possibility was discussed with JSC personnel during the March 2-3, 1977 quarterly review. The positive response to this option resulted in the preparation of a plan for installing a Data 100 remote terminal at JSC. This plan, which is presented below, was transmitted to Mr. Don Hay on April 1, 1977.

o o 0 0 o o

PLAN FOR INSTALLATION OF DATA 100 REMOTE TERMINAL

Howard L. Grams
Terry L. Phillips
Laboratory for Applications of Remote Sensing
Purdue University
March 1977

This document is intended to present specific details of the proposed implementation of hardware enhancements to the existing remote terminal located at the Earth Observation Division at the Johnson Space Center. The hardware currently includes an IBM 2780 system and is connected to the Purdue/LARS computer. The terminal can be upgraded to allow functions to be performed that now cannot be performed at all, and to allow functions that can be performed now to be performed faster or more conveniently.

The proposed hardware is expected to be significantly more reliable than the present hardware. The "human factors" aspect of using the new hardware should be improved from that of the present hardware, and the retraining aspect is expected to be minimal to perform present functions.

The proposed change is to replace the present IBM 2780 terminal with an upward compatible terminal. At present this is expected to be a Data 100 Model 78 as described in the subsection entitled "Tentative Hardware Budget". The new terminal would have a magnetic tape capability that could be used either as a source for data sent to the LARS computer or a sink for data received from the LARS system. The new terminal would otherwise be compatible with the existing 2780 (it can read cards, print output, and punch cards). In some cases these functions would be faster than those of the 2780 and also more convenient from a human factors point of view.

In addition, the existing Codex 7200 modems and 800 multiplexors would be replaced with newer hardware that allows higher speed transmission. However, the existing C2-conditioned phone line would still be used.

The benefits and purposes of the new terminal are included in this report as well as a milestone plan for installation.

Benefits and Purposes

The proposed implementation is an amalgam of need, ideas, wishes, and suggestions from both JSC and LARS personnel. Its benefits include (but are not limited to) the following:

A. Allow JSC personnel to send test data to LARS so they can have it immediately available to use for research, test, and evaluation efforts using the LARS computer hardware/software systems.

B. Provide means for JSC personnel to test and evaluate the ECHO technology presently under development at LARS. This would be facilitated by enhanced access to the algorithm implementation on the LARS computer as well as by the capability to quickly and conveniently send test data.

C. Improved access to the Field Measurements data base for EOD personnel at JSC.

D. Enhance the present operational procedures at JSC for CAMS/CAS by providing a more convenient medium (magnetic tape) for the operation than presently used (punched cards) for data read into software in the LARS computer and output from that software.

MILESTONES

This discussion is centered around a possible proposed scenario, with certain assumptions made concerning starting dates, necessary decision dates and so forth. A milestone chart for this scenario is attached. It should be noted that any delay of each particular milestone will produce a corresponding length delay in all other milestones downline.

DATE	RESPONSIBLE	DESCRIPTIONS
May 1	Purdue	Submit proposed hardware specifications to JSC. This includes physical site requirements information.
June 1	JSC	Make final decision to proceed with project. Approve funding arrangements. Approve the choice of hardware recommended by Purdue for procurement.
October 1	JSC	Order hardware for the terminal and modems by July 1. Since delivery time is expected to be 90 days, any delay will cause the final installation date to slip a corresponding amount. Order power installation and physical site preparation. Install power receptacles and have physical site for new terminal hardware ready by September 15. Install new terminal hardware, modems, and related equipment on October 1.
August 1	JSC	Approve plans presented on July 1 by Purdue for software development to support the new tape drive capability.
August 1	JSC	Approve plans presented on July 1 by Purdue for retraining terminal users.
November 1	Purdue/JSC	Complete retraining of users so that 2780 can be removed. Complete testing of new hardware to insure it performs all current functions. Complete testing and declare operational the new functional capabilities that utilize the magnetic tape unit. Train users at JSC in its use. Remove 2780 hardware.
November 15	Purdue/JSC	Meet to evaluate the results of the project and the state of implementation of the functions using the new magnetic tape hardware. Identify problem areas for future effort.

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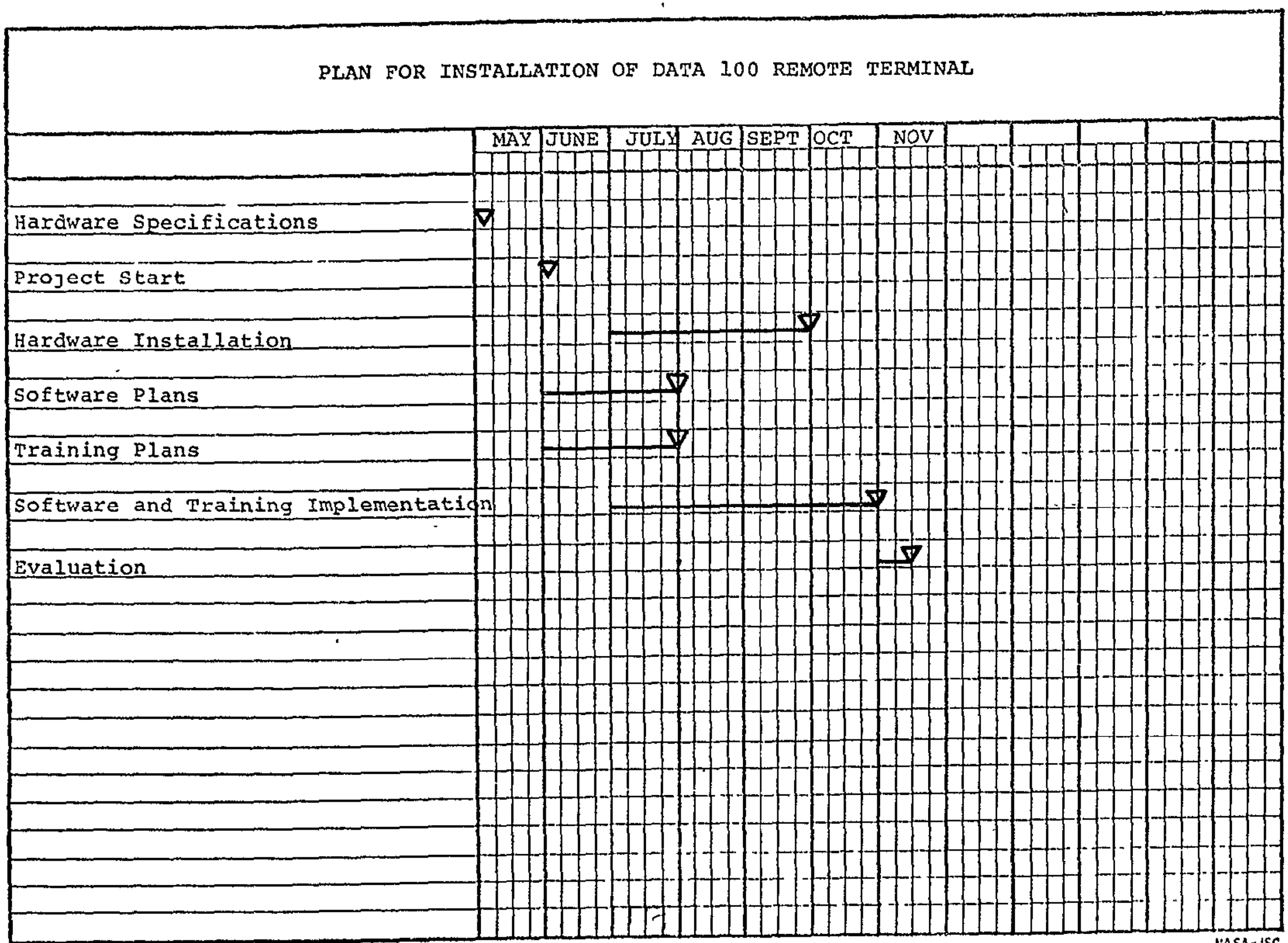

ISC Form 1956C (Rev Jun 68) NASA-JSC

Tentative Hardware Budget

The proposed new hardware to replace the existing IBM 2780 terminal is a Data-100 Model 78 terminal with a magnetic tape capability. Although this hardware is available for lease (12 months minimum, month-to-month thereafter) or for purcahse, it is recommended to lease since LARS expects to develop even more cost effective hardware in the reasonably near future.

The hardware suggested includes:

78-111	Terminal Control Unit	$355/mo
8801	IBM 2780 Emulation Feature	26/mo
8130	Card reader adapter	13/mo
8132	Card punch adapter	102/mo
8140	Line printer adapter	40/mo
8190	Magnetic tape adapter	82/mo
78-202	9-track 1800 bpi Magnetic tape	219/mo
8878	4K MT Blocking feature	32/mo
78-304	150 CPM Card Reader	109/mo
78-302	Card Punch	288/mo
78-405	400 LPM Line Printer	596/mo
8442	132 Column Option	77/mo
78-702	RS-232 Synchronous Communications	98/mo
8721	9600 BPS option	40/mo
	TOTAL	$2,077/mo

The proposed modem configuration consists of:

2	Codex LSI-96 Modems @$185/mo	$370/mo
1	Codex 910 multiplexor with RAM	124/mo
1	Codex 910 multiplexor with dual RDM	114/mo
	Miscellaneous Options (Mounting HW, cabling, etc.)	~20/mo
		$628/mo

Dual Configuration RDM for multiplexor (purchase) $180 o o 0 0 o o

We are currently waiting to receive a response from JSC with regard to this plan.

<u>LITER Development</u>. The concept of an improved remote terminal based around a minicomputer supported by an array of special purpose and general purpose peripheral equipment was described in the June 1 - August 31, 1976 quarterly progress report. Progress on the development of this terminal, known as the LARS Intelligent Terminal for Earth Resources (LITER), during the past year has been limited. This is due to the relatively low funding level and, as reported in the September 1 - November 30, 1976 quarterly report, a decision, based on discussions with JSC, to lower its priority in favor of raising the priority of proposing solutions to JSC's expressed need to have an improved capability for transmitting data over the remote terminal link.

Progress which has been made during the past year falls into three categories--planning, equipment installation, and capability demonstrations.

> Planning -- Implementation of the concept has been planned in three phases: I - a developmental prototype, II - implementation of user oriented software, and III - hardware additions and further enhancement of the system software. Only a portion of Phase I has been completed this year.
>
> Equipment Installation -- The following equipment associated with the LITER system has been installed and tested:
>
> PDP - 11/34 Minicomputer
> Varian 4211 Electrostatic Printer/Plotter
> Talos 660B Table Digitizer
> Infoton Vistar/GTX CRT terminal
>
> plus necessary interface equipment.
>
> Capability Demonstrations -- Progress in demonstrating the capabilities of the LITER system has been limited. Each of the major capabilities of the system have been tested and sample products produced but little progress has been made in documenting the system capabilities.

Development of Education and Training Materials. During the past year there has been a shift in emphasis with regard to the development of education and training materials under SR & T support. Effort on materials dealing with fundamental concepts and current application tasks has been decreasing and an increase in effort has been made in the development of materials to support the transfer of new technology to JSC. This reorientation of priorities is consistent with the proposed plans to upgrade the JSC/LARS remote terminal to make it a more effective tool for the test and evaluation of new analysis procedures.

A) Items completed. LARS Information Note 052977 entitled "The FOCUS Series: A Collection of Single-Concept Remote Sensing Educational Materials" was published this past quarter. This Information Note is a compilation of all titles in the FOCUS series, each of which consists of a diagram or photograph and an extended caption of three to four hundred words treating a single concept. Purposely intended to be brief, individual titles in the series do not lend themselves to being submitted as technical reports. In order that the existance and rationale behind the series may be disseminated, the titles currently available have been collected in this Information Note.

B) Items in progress. An analysis case study is being developed in order to provide education and training in the use of the supervised ECHO classification algorithm. The case study is scheduled to be completed within three months after the release of the ECHO software. Unlike the case studies developed for 2780 remote terminal training the ECHO case study is being written so that it is not dependent upon a particular hardware configuration. This will give the case study wider utility and will facilitate the test and evaluation of the ECHO processor as it might be implemented on JSC's computer system. The new format essentially simulates a batch mode computer environment. The case study is divided into a number of steps corresponding to the analysis sequence. The student will interact with a tutor at the conclusion of activities stratigically placed through the materials. Appropriate computer printouts will be available at key points simulating a batch machine operation.

Two data sets have been selected for use in the case study. One will be used to provide a detailed analysis example, the other will be used in a series of exercises. Persons working the exercises will independently complete an ECHO classification using available computer facilities.

Each step in the analysis will be discussed at three levels: an overview describing the purpose, objectives and techniques used; a second level dealing with the specifics of a sample analysis; and, a third level which will allow the student to carry out his own ECHO analysis. A draft of the case study has been completed and is presently undergoing internal review.

Proposed Technology Transfer Milestones. Figure 2.5-3 shows a proposed set of technology transfer milestones through 1980. The major milestones include installing and supporting a Data 100 terminal at JSC, and demonstrating the feasibility, installing and supporting a LITER terminal at JSC. These long term objectives are all aimed at providing a significantly improved remote terminal which can serve the research, test, and evaluation needs of JSC.

Plans for Next Quarter. Plans for activities under this task during the next quarter center around the Data 100 Installation Plan milestones (see page 2.5-5 through page 2.5-9). In addition to the items specifically mentioned there the ECHO Case Study is scheduled to be completed during the next quarter. Its use will be incorporated into the Data 100 terminal training plan in order to demonstrate how the remote terminal system can serve as an RT & E tool. Proposals for using the terminal to evaluate Procedure 1 (P1) will also be part of the Data 100 training plan.

Problems. Purdue/LARS has not received any response from NASA/JSC concerning the Data 100 Installation Plan. Delay beyond June 1, 1977 will cause a corresponding delay in installing the terminal.

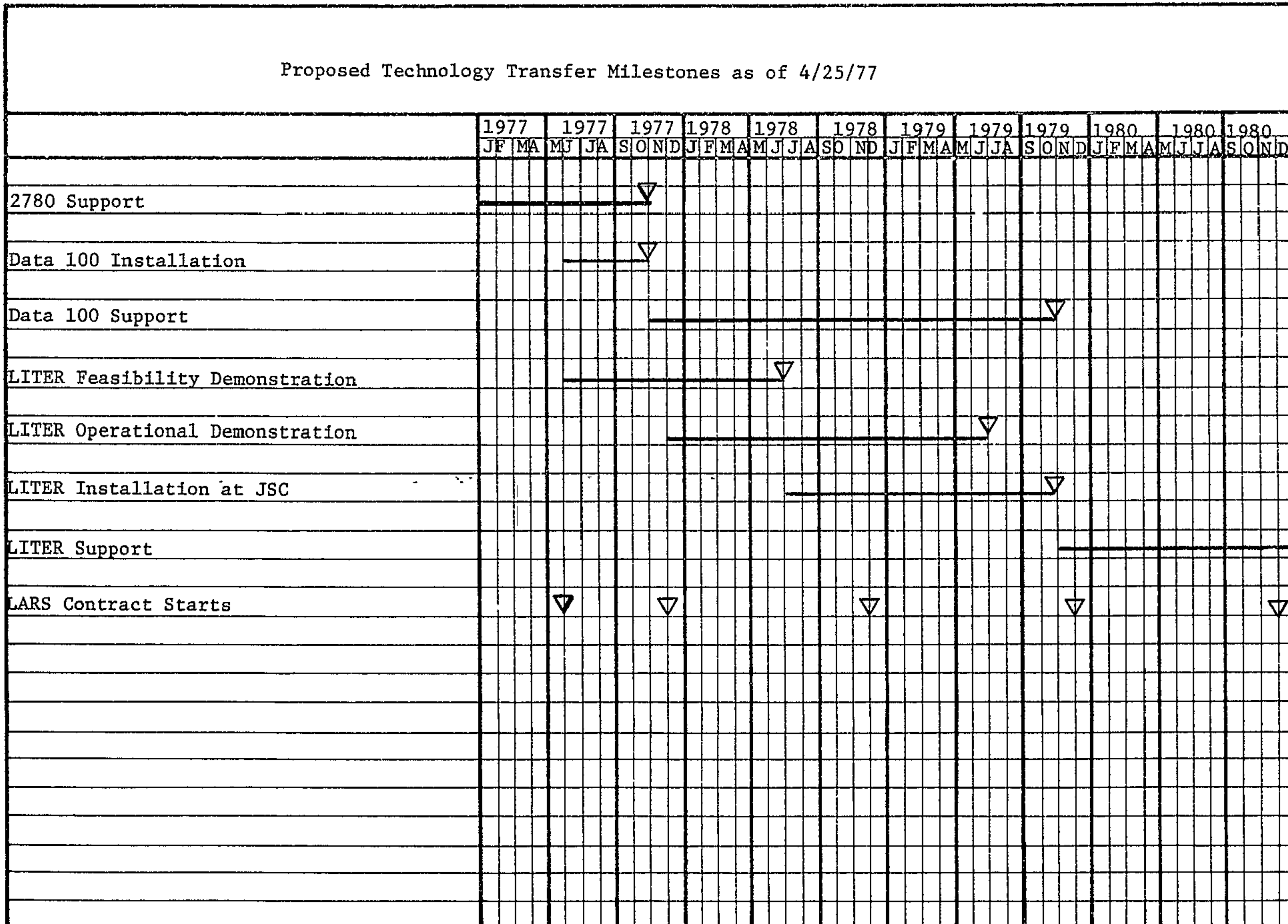

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Figure 2.5-3

2.6 Large Area Crop Inventory Design

In March the Large Area Crop Inventory Design (LACID) task at the request of NASA/JSC began to concentrate its activities on the requirements for a food and fiber information system. On March 30-31, R.B. MacDonald and three of his staff met with staff and several department heads of the Purdue School of Agriculture to explore possible roles of the School and LARS in assisting JSC to define the information requirements of a global food and fiber information system.

As a result of these and later meetings involving the School of Agriculture administration, the Implementation Committee was encouraged to proceed with organizational and work plans for implementation of the study.

Four staff members of the School of Agriculture are meeting regularly to implement the study. This group, known as the Implementation Committee, is composed of Prof. Marion Baumgardner, Chairman, Agronomy; Dr. Marvin Bauer, Agronomy/LARS; Marshall Martin, Agricultural Economics; and Robert Peart, Agricultural Engineering. An advisory committee of 20 scientists from nine departments has been named. This committee will provide counsel for Implementation Committee and review materials prepared by the Implementation Committee. Several potential consultants with experience in agricultural policy, rangeland and forestry have been contacted.

At the present time we are acquiring and reviewing reference materials and reports from previous studies which may have a bearing on the definition of a global food and fiber information system. The proposed schedule of activities calls for completion of detailed proposal of objectives and approach by mid-June. Plans are being made for a workshop in September with participants from the scientific community, agricultural industries, and international development organizations.

2.7 Forestry Applications Project

Introduction

This task activity has been directed toward the development of inventory schemes which utilize Landsat data and computer-aided analysis techniques. The ultimate objective is aimed at developing various approaches for using Landsat data to conduct inventories of the 1.6 billion acres of forest and range land resources in the United States. Emphasis is being placed on effective, statistically sound approaches which a-priori inputs, such as climate, topography and previous inventory information.

Background

The approach has developed through several phases, each becoming better defined and structured than the phase proceeding. The initial phase or activity dealt with a review of forest inventory literature which emphasized sampling techniques developed since the launch of Landsat 1. The best focus for the project was acquired through a review of the 1975 assessment of the Resources Planning Act completed by the U.S. Forest Service. The result of the review is summarized in Table 2.7-1. Specific needs were identified that could be addressed through the application of remote sensing technology.

During the second phase our attention was focused on the forestry sector of the Resources Planning Act. Specifically, we worked to define how a Landsat analysis system could benefit the ungoing forest survey activity conducted by the Forest Experiment Stations. In Effect the task objective had been narrowed from broad-based large-scale surveys to regional single purpose surveys. By so doing, we were able to define benchmarks (forest survey standards) against which we could assess the effect of Landsat inputs.

Table 2.7-1. Summary Review of Resource Planning Act Assessment (1).

System	Unit of Measure (2)	Measurable by R. S. (3)	Beneficient to Decision (4)
Timber			
Type	Area	+	D
Ownership	Area	0	I
Productivity	Volume	0	I
Range			
Type	Area	+	D
Ownership	Area	0	I
Productivity	Volume	0	I
Water			
Type-Impounded	Area	+	D
Flowing	Area	0	I
Use	Volume	-	I
Fish and Wildlife			
Habitat Type	Area	+	I
Population Estimates	Census	-	I
Recreation and Wilderness			
Participation	Census	-	I
Human and			
Community Development	Economic	-	N

(1) ref: The Nation's Renewable Resources-An Assessment, 1975, USDA-Forest Service.

(2) General classification of units of measure reported in (1).

(3) Measurable by remote sensing techniques.
Includes all measures possible from satellite and/or aircraft systems.
+ Directly measurable from satellite or aircraft data alone.
0 Measures can be inferred with the support of ancillary type data.
- Measure which is not even indirectly affected by satellite or aircraft inputs.

(4) Benefit of Remote Sensing inputs to Decision Process.
Inferred based on inputs.
D - Direct not utilizing other inputs.
I - Indirect utilizing other inputs.
N - Not Obvious.

Forest Survey is required by congress to meet certain pre-defined standards for measuring the areal extent (expressed in acres) and quantity (expressed in cubic feet) of the available resource. Our study indicated that most sampling schemes considered quantity of the resource a critical variable, while area, which is the most easily measured parameter from Landsat, is all but ignored. Therefore, most of these approaches require complex statistical manipulation of various data sources to identify field plots which are necessary in order to acquire volume.

Forest Survey, depends on estimates of forest acreage in order to allocate field plots. If we assume that a Landsat system can accurately measure areal extent of forest, then we may anticipate some improvement over the current approach. The second phase was directed toward formulating assumptions which could be used to answer the question relative to Landsat's ability to provide the acreage inputs necessary for Forest Survey.

In addition, we are preparing to investigate the utility of the Forest Survey permanent remeasurement plot network to the design. Plot data is being collected for sites in Indiana where Landsat data is available. The relationship of field measured parameters to spectral response will be studied. Finally, an assessment of the utility of this data to the design problem will be made.

Phase three of this task will identify recommended approaches to the inventory problem.

Approach

After review of the Resources Planning Act Assessment of 1975 and Forest Survey requirements, we outlined a general approach for the use of Landsat data. The approach is graphically displayed in Figure 2.7-1. Table 2.7-2 details the anticipated use, potential benefits and detail of ancillary input required for each level of classification intensity.

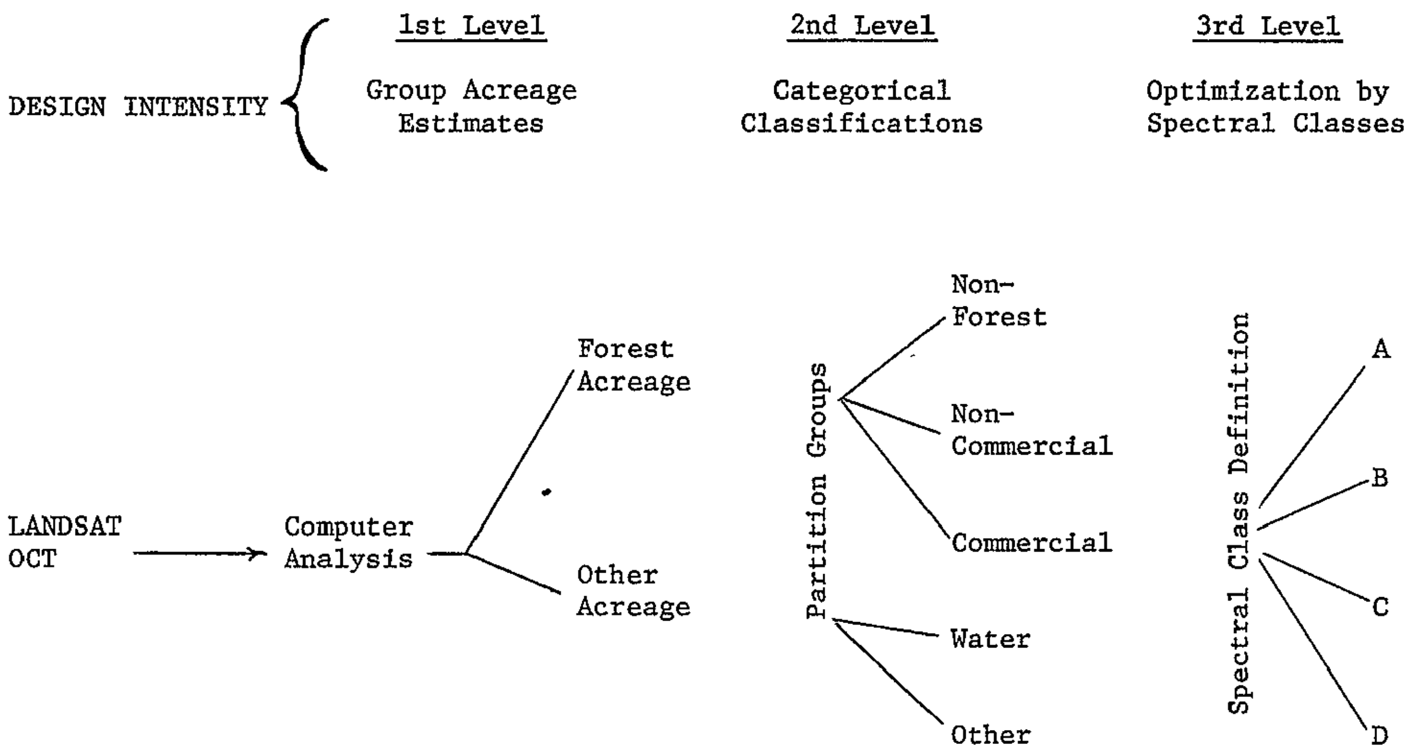

Figure 2.7-1. Schematic flow anticipated in design definition.

Table 2.7-2. Anticipated use, potential benefits, and ancillary data inputs for the various levels of classification intensity.

Design Intensity	Input from Landsat Analysis	Unit	Level of Use	Potential Benefits	Ancillary Data Needs
1st level	Forest Non-Forest	Acres	- Proportional allocation of points for intensive airphoto and ground	- Timeliness - Speed of Analysis - More Objective	- Maximum ancillary data needs (air photo & ground) - Minimum input, only acreage - Maximum photo and field plots
2nd level	Non-Forest (< 10% cover) Commercial Non-Commercial	Acres	- Same as level 1 - could optimize plot allocation based on previous inventory	- Same as level 1 - Minimize temporary plot location and field work - Improve allocation of field work - Increase efficiency of survey - Decrease frequency between surveys - Yearly monitoring of forest change	- Possible decrease in field plots - Probable reduction of photo plots
3rd level	Information Partitions Within Commercial Forest	Acres	- Same as level 2	- Same as level 2 - Improve efficiency - Improve yearly prediction of available resource supply - Monitor forest change in greater detail	- Minimize amount of ancillary inputs (fewer photo points, no temporary plots)

This approach assumes that Landsat data can be used to delineate areal extent of forest test areas, consisting of counties within the Great Lakes Watershed will be used as benchmarks against which Landsat classifications will be compared. Data are currently available for Michigan and Wisconsin, and are being acquired for Minnesota and New York. Statistical tests will be run on the Landsat and Forest Survey results.

The efficiency, or timeliness, of obtaining classification results from Landsat are of concern for the inventory design. Any advantage of a Landsat based inventory system may be greatly diminished if the time required to produce the acreage estimates was greater than or equal to current procedures.

A small study has been defined to provide quantative information on classification time. Carlton County, MN is being classified using both a maximum likelihood approach and a levels slicing approach. The "levels" approach offers a potential savings in classification time given the analyst has sufficient or prior knowledge to set the levels. The time required to achieve similar classification accuracies for a forest/non-forest breakdown will be composed. Recommendations regarding the "levels classify" approach as part of a multi-level sampling strategy will be made in the final report.

The second level of classification intensity is intended to optimize a prior knowledge about the forest resource through use of Forest Survey permanent sample plots. Figure 2.7-2 shows a portion of a field plot sheet used to record permanent plot data. Approximately 30 such plots are available for two sites in Indiana. These data are currently being studied to determine how they can best be used.

The last level of classification intensity, the level of maximum information detail, will not be addressed by this study. Level 3 knowledge assumes that a high correlation exists between spectral categories and useable information. The investigation into this level of detail is beyond the scope of this task. Based on our understanding of the scene components and the current technology we will be prepared to make recommendations regarding future areas of study.

Sequential plot #____________________

NC-4800-11 FOREST INVENTORY SAMPLE RECORD April 1967

AREA IDENTIFICATION						LAND USE							AREA CLASSIFICATION	Species Height Age					Forest Type			OPTIONAL			
STATE	UNIT	COUNTY	SAMPLE NUMBER	SAMPLE KIND	DATE OF SURVEY	DOT	P. I.	GROUND	USE TREND	OWNERSHIP CLASS	NATIONAL FOREST	WORK CIRCLE	STAND ORIGIN	Site Class	Site Index	Physio Class	STAND-AGE	SEED SOURCE	FOREST SURVEY	NFA	STAND-SIZE CLASS	B A./ACRE	TREATMENT	START NUMBER	DOT NUMBER
1	2	3	4	5	6	7	7	8	9	10	11	12	50	51	52	53	54	55	56	56A	57	69	70	71	72
XX	X	XX	XXXX	X	XXXX	XX	XX	XX	XX	XX	XXX	X	X	X	XX	X	XX	X	XX	XX	XX	XXX	XX	X	XXX

TREE IDENTIFICATION						TREE MEASUREMENTS							TREE CLASSIFICATION								OPTIONAL			
AZIMUTH	DISTANCE	POINT NUMBER	TREE NUMBER	TREE HISTORY	SPECIES	D. B. H.	BOLE LENGTH	CULL CUBIC FEET	SAW LOG LENGTH	SAWLOG TOP D O B.	CULL BOARD FEET	LOG GRADE	SURFACE DEFECT	INTERNAL DEFECT	TOT VOLUME LOSS	RELATIVE BOLE LENGTH	CROWN RATIO	CROWN CLASS	DAMAGE-CAUSE OF DEATH	TREE OR COVER CLASS	POINT OCCUPANCY	STOCKING PERCENT	BOLE LENGTH TOP D O B	CUT OR LEAVE
13	14	15	16	17	18	19	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
XXX	XXX	X	XX	XX	XXX	XXXX	XXX	XXXX	XXX	XXX	XXX	X	X	X	X	X	X	X	XX	X	X	XX	XX	X
						0																		
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Figure 2.7-2 Portion of forest inventory field record showing the type of information collected for permanent field plots.

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2.8 Regional Applications Project

Objective

The overall objective of the Regional Applications Project was the development of a computer procedure for (1) inventorying and categorizing Texas coastal zone environments and (2) monitoring and identifying significant alterations in these environments.

Within this objective was the goal of identifying and delineating primary level coastal zone features based upon the association between Landsat multispectral data and known ground truth information. On site inspection, interpretation of aerial photographs, and Texas Bureau of Economics Geology maps were to form the ground truth information.

Approach

Previous research by Purdue/LARS involved the classification of Landsat MSS data to produce an inventory of environmental units within the Texas Coastal zone. For the 1976/77 contract year, the emphasis was to be on the development, refinement, and documentation of a change detection procedure. This effort was to incorporate the comparison and analysis of Landsat MSS data accumulated over different time periods for the Matagorda Bay Coastal Zone study site (three USGS 7½ minute quadrangles, i.e., Pass Cavallo, Austwell, and Port O'Connor). In the development and refinement of a change detection procedure, the following efforts were to be accomplished by Purdue/LARS: (1) Determine the extent to which detectable seasonal changes in the coastal zone classifications could be identified. (2) Determine the extent to which detectable permanent changes in the coastal zone classifications could be identified. (3) Determine methods for delineating between seasonal and permanent variations for specific coastal zone features. (4) Register detected change classes to 1:24,000 USGS quadrangles using existing LARS capabilities. (5) Define significant changes to be established by the user agency, i.e., (State of Texas). Using these definitions a measure of the degree of accuracy of the change detection procedure was to be made. (6) Transfer the change detection procedure with software, algorithms and user documentation to NASA/JSC.

Accomplishments

The accomplishments under this task, a six-month investigation terminated by the sponsor on 30 November 1976, are summarized as follows.

Of the four change detection techniques investigated during the past contract year (post classification comparison, delta data, spectral/temporal, and layered spectral temporal), the post classification comparison technique was selected for further development. This was based upon test performances of the four change detection methods, straightforwardness of the procedures and the output products desired.

A standardized "modified" unsupervised classification procedure for analyzing the Texas Coastal Zone data was compiled. This procedure was developed in order that all quadrangles in the study area would be classified using similar analysis techniques to allow for meaningful comparisons and evaluations of the classifications. Single date classifications were completed for the three quadrangle areas for the February 25, 1975 date. These classifications were to be used as the base data to which classifications developed from the later three dates were to be compared in order to analyze the post classification change detection technique and to develop a standardized change detection procedure.

A "modified" unsupervised approach was used to classify the Austwell quadrangle. The Spectral Environmental Overlay in conjunction with February 1975 CIR photography was used to choose training areas. The resulting classification contained 35 spectrally separable classes which appeared to characterize the scene completely.

Since the Spectral Environmental Overlay contained only 25 classes, a one-to-one correspondence between the overlay classes and the 35 spectral classes could not be established. Preliminary comparisons show that some classes of the hierarchical classification are represented by more than one spectral class, and there are some hierarchical classes (e.g., TFi, WB) that are not represented in the spectral classification of the Austwell area. The absence of these classes can be explained either by there being so few data points available to use as training samples to represent the classes or the classes are not spectrally separable from other classes. It appears that the latter case may prevail. Grouping of certain members of the 35 spectral classes was done to gain the maximum correlation between the spectral classes and the hierarchy classification.

Thus, an additional task involved the modification of the spectral hierarchy developed by JSC/LEC. The original hierarchy was developed using photointerpretive information such as texture, spatial distribution, subjective cultural interpretations and spectral response. Since the Landsat multispectral scanner records data predominantly spectral in nature, any hierarchy to be used with scanner data must be spectrally derived. Table 1 lists the 35 spectral classes identified in the Austwell quadrangle area and their corresponding JSC/LEC hierarchical classes. The final version of the modified spectral hierarchy was not completed.

Another area of involvement consisted of investigation of methods for improving the geometric accuracy of the registered coastal zone quadrangles.

In the Port O'Connor quadrangle there are no control points in the lower right quarter since this is an offshore region. A one-to-two line geometric stretch error is observed and this is thought to be due to the effect of inaccurate quadratic terms caused by poor point distribution. The original geometrically corrected Port O'Connor quadrangle data were inspected to obtain all possible ground control point locations. The same points were located in the uncorrected data and on the USGS map used as a geometric reference. The mathematical functions tested were the affine and the collinearity geometric corrections. The results of these methods were compared to the least squares bi-quadratic method used in the original corrections. The methods were tested by selecting check points in the lower water covered portion of the Port O'Connor quadrangle where no control points existed. Results indicated that the affine geometric correction function is the most accurate of the two tested in areas where control points are not well distributed over the area to be corrected.

The RAP simulation study was completed during this period. This study consists of a documented procedures package for classifying the Pass Cavallo quadrangle in the Texas Coastal Zone. This package will be valuable in transferring analysis technique procedures, as applied to coastal zone features, to persons new to data analysis or coastal zone environments.

Technical Problems Encountered

The most serious difficulty encountered during this effort was the lack of available data for use in developing procedures.

Recommendations

Work should continue on the development of procedures for inventorying and monitoring the Texas Coastal Zone. However, for this effort to be successful, a positive effort must be made to collect adequate reference data coincident with the desired Landsat overpasses. Without coincident reference data performance criteria cannot be properly evaluated.

Even though the post classification comparison change detection technique was selected for this portion of the study, it is felt that the layered spectral/temporal change detection procedure holds great promise for monitoring change. This technique should be reevaluated when an appropriate data set (coincident reference and Landsat data) has been assembled.

SPECTRAL CLASS DEFINITION - AUSTWELL QUADRANGLE

Spectral Class	Class Definition	Hierarchical Class(es) Represented
1	low vegetative cover on light (bright) soil	He, Heg
2	sparse low vegetation	Het
3	mixed woody/herbaceous cover-fairly green	Mdg, HGg, some Md.
4	wet herbaceous-lush cover	He, some Het, Heg.
5	herbaceous-covered with water	Hei
6	herbaceous-complete inundated	Hei
7	mixed-woody and herbaceous-fairly dense	He, Wf
8	bright bare soil-wet spread all over in the delta	Bst
9	herbaceous-wet-occurring mainly in the delta	Hei
10	standing water, dark-low reflectance-some vegetation	some Hei
11	herbaceous-farily dense	He
12	herbaceous emergent wet	Hei, Heg
13	sparse wet herbaceous-low spectral response	Hei, He
14	sparse wet herbaceous-low spectral response-few points occurring alongside class 13	Hei, He
15	bare soil wet	Bst
16	water in pond next to the refinery (?)-high reflectance in class 2 indicating high turbidity-or some pollutant-or red suspended sediment	MMw
17, 18 19, 20	Sea water classes	W
21	bright soil (sandy slightly inundated-fringing around shallow water ponds and in the delta	Bs, Ws
22	sparse vegetation on light colored soil that is wet-few points in the delta	Heg
23, 24	mixed pixel response-bare soil and wet vegetation scattered in the lower delta region and along the coast	---

Spectral Class	Class Definition	Hierarchical Class(es) Represented
25	"edge" water class-occurring along the coast and fringing shallow water areas in the delta	Ws
29, 30	bare soil tilled and wet	Bst
31	bright wet surface (concrete) delineating the refinery	MMu
32, 33	very few points picking up the commercial in the city residential class	MMu
34, 35	sea water in the bay area	W
26, 27 28	shallow water	Ws

2.9 Interpretation of Thermal Band Data

Revision of Implementation Plan

This is a continuing project in a contract extension and a quarterly report will be given here in lieu of a previously planned final report. The implementation plan is to be revised to this extent with subsequent impact on the milestone chart.

Major Activities. A simplified radiation model intended to utilize the experimental data acquired previously has been studied in this quarter. The objective was to produce a model that would predict the effective radiant temperature of the canopy under study, in this case North Dakota Spring and Winter Wheat, as a function of view angle (θ',ϕ') where θ' and ϕ' are the viewing zenith and azmuith angles respectively. The radiant temperature would presumably be a function of canopy geometry, solar input power, and soil type. With proper agronomic characterization the canopy geometry can ultimately be correlated to the yield of the crop.

Generally two basic approaches could be used: a rather complex model that relies on easily produced experimental data or a simple model that depends on a relatively complex experiment. The latter was chosen because of the difficulties encountered by many investigators in mathematically describing a complex structure like wheat.

The model chosen uses a one-layer structure with the heated soil at the bottom and the tips of the plants at the top. The quantities needed to support the model are the radiant temperature profile $T(z)$, where z is the vertical distance in the canopy (soil surface at $z = 0$)

and the view factor $P(z,\theta',\phi')$ which describes the probability of viewing the sky at any height z in the canopy in the direction (θ',ϕ'). The view factor is directly relatable to the canopy geometry and indirectly to the canopy yield. If continuous functions were available the radiant temperature of the canopy in direction (θ',ϕ') would be given by

$$f_2(T_V(\theta',\phi')) = \int_0^{z_c} P(z,\theta',\phi')\ f_1(T(z))\ dz.$$

f_1 is derived by applying radiation heat transfer principles to T(z) and $T_V(\theta',\phi')$ is derived by inverting f_2 which is also based on radiation heat transfer principles. In practice, however, continuous functions are not available and the model uses discrete approximations to the above functions.

T(z) is obtained using procedures described in previous quarterly reports. The experimental setup is schematically described in Figure 2.9-1 and is shown photographically in Figure 2.9-2. Some typical data products are shown in Figure 2.9-3. Note that the thermal scanner is arranged to scan vertically through the canopy and the line scan data shown in Figure 2.9-3 B and D, when calibrated, directly yields T(z). In all cases the radiant existance is interpretated as emitting from a target with an emittance of unity prior to the calculation of the radiant temperatures.

The view factor $P(z,\theta',\phi')$ is obtained experimentally using procedures described in LARS Information Note # 120776 (A Laser Technique for Characterizing the Geometry of Plant Canopies; Vanderbilt, Silva and Bauer). The procedure involves the utilization of a laser to

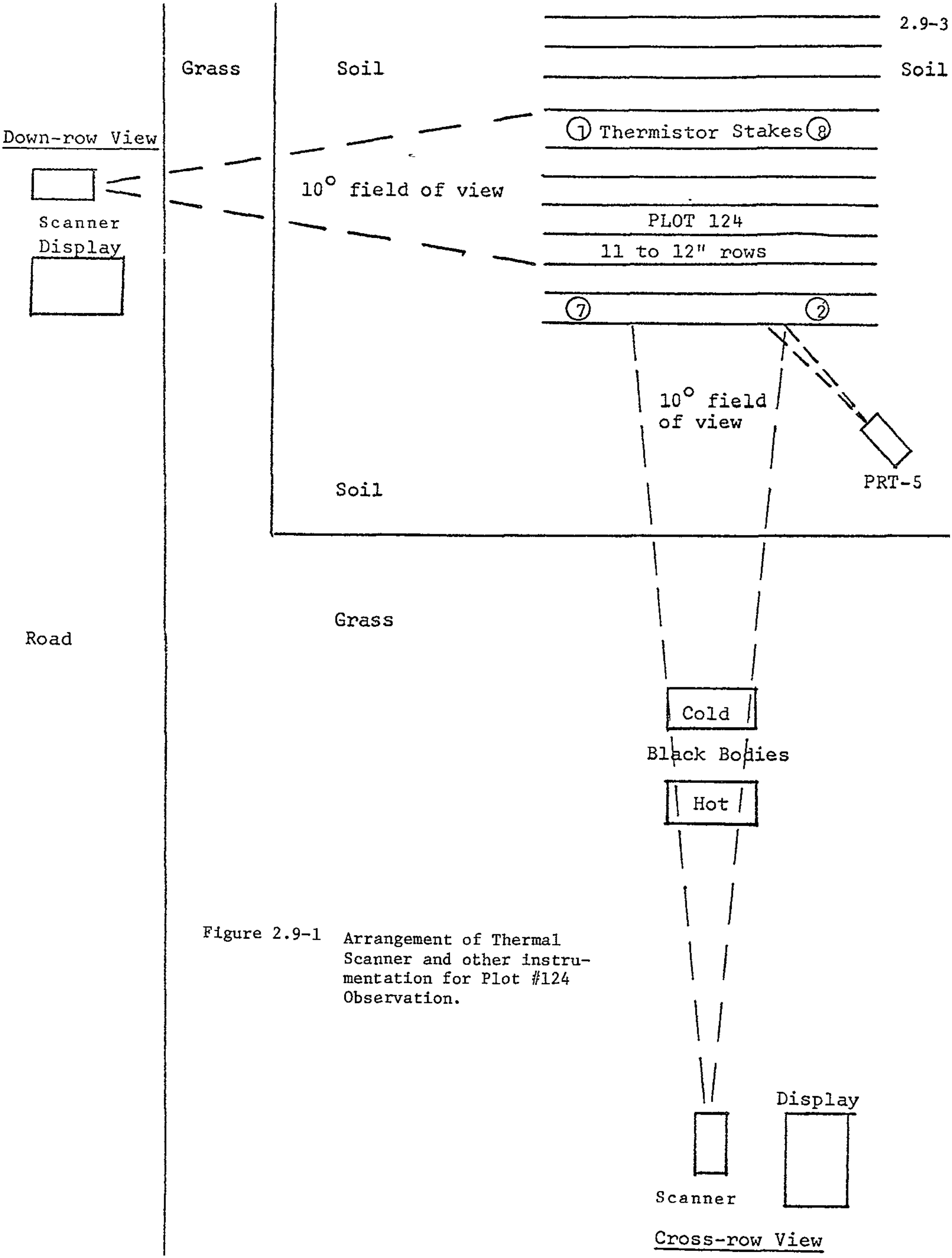
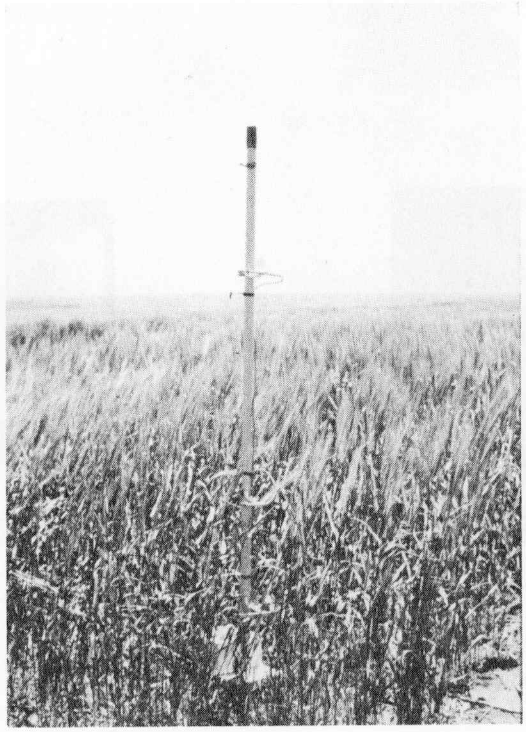


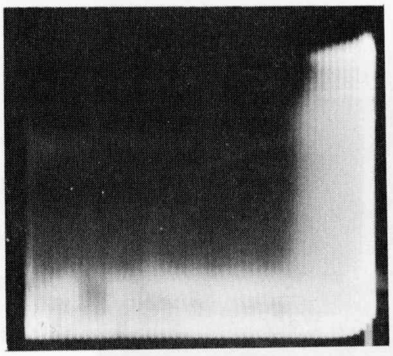
Figure 2.9-1 Arrangement of Thermal Scanner and other instrumentation for Plot #124 Observation.



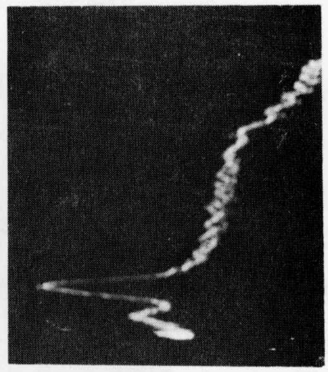
(A) Thermistor Stake in Wheat Canopy

(B) Arrangement of Instrumentation

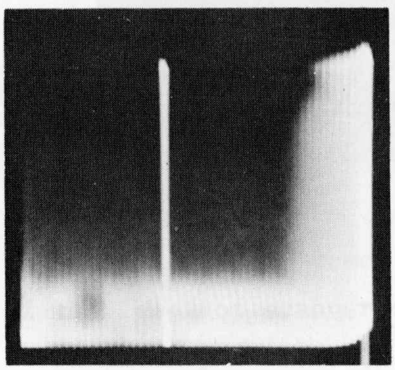
Figure 2.9-2 Photograph of the Thermistor Stake and Instrumentation Arrangement (Plot #124, 17 June 1976)



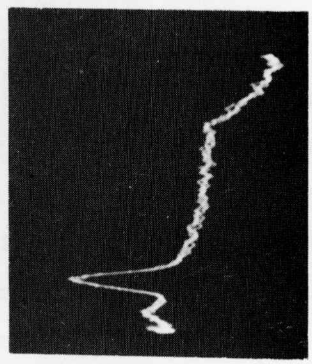
(A) Thermal Image, full sunlight (local time 1425)



(B) Line Scan, full sunlight



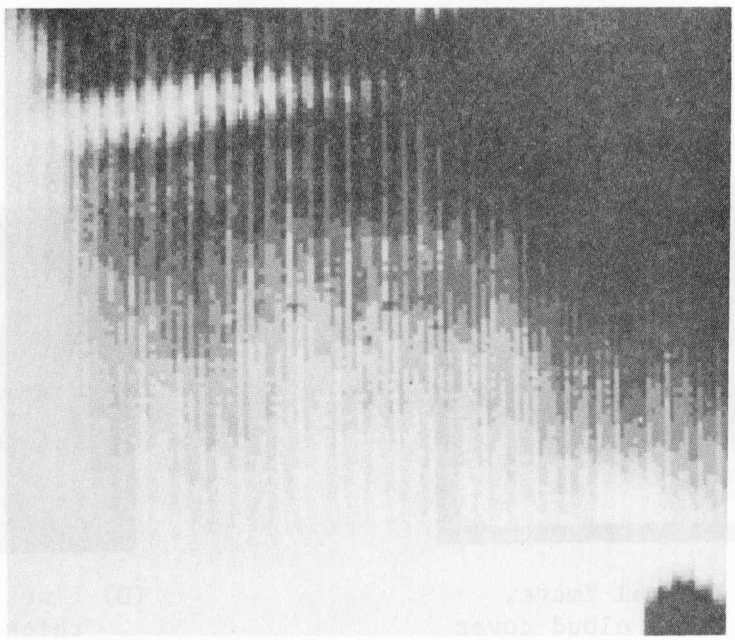
(C) Thermal Image, thick cloud cover (local time 1428)



(D) Line Scan, thick cloud cover

Figure 2.9-3 Side Thermal Images and Line Scans (Plot #124, 17 June 1976)

(A) Canopy Side View



(B) Digitized Thermal Image

Figure 2.9-4 Photograph and Digitized Thermal Image, Side View of Canopy
(Small Grain Test Plot #7, 10 July 1976, local time 1801)

optically probe the canopy. The laser is aimed into the canopy at several zenith angles (θ'). Initially azmuith (φ') effects have not been considered. In order to adequately characterize the canopy sufficient laser data must be acquired. If data are taken over a range of zenith angles from 5° to 75° in 10° steps eight groups of laser data will result. For at least 1% quantization accuracy 100 laser hits are required in each angular group of data. To account for canopy variability at least three replications of the data are needed which means that 8 x 100 x 3 = 2400 laser hits are required. The laser technique is intended to be utilized with an automated system. Budget restrictions forced the use of a manual system and, unfortunately, insufficient data were take to adequately characterize the canopy. As a result the radiation model cannot be fully evaluated with available data sets.

An experiment has been planned for the summer of 1977 in conjunction with the Field Measurements Research project that uses a modified laser technique, basically manual, that should yield sufficient data to characterize the canopy. A backup photographic technique will also be used in case the proposed laser technique proves to be too cumbersome. The thermal measurements will be repeated in one series of experiments during July, 1977, at the Williston, N.D. test site.

Technical Problems and Solutions. Insufficient laser data were taken to adequately characterize the wheat canopy under study. A revised procedure has been developed for a limited series of experiments in July, 1977, that should yield sufficient data to support the radiation model.

Plans for the Next Quarter. Additional experimental data will be taken to support the radiation model.

2.10 Super Site Data Management

Major Activities

The quarter's activities include continued work towards verifying and documenting the quality of the truck-mounted and helicopter-mounted spectrometer data. A Field Measurements Spectral Data Verification Report is being written which discusses the quality and the correlation of the data for the major sensors. The sections planned at present for the report include

1) Spectrometer Calibration Method
2) NASA/JSC Field Spectrometer System (FSS) Data
3) NASA/JSC Field Signature Acquisition System (FSAS) Data
4) Purdue/LARS Exotech 20C Data
5) NASA/ERL Exotech 20D Data
6) Spectrometer Systems Data Correlation
7) Aircraft Multispectral Scanner Data

FSS(S-191H) Spectrometer Data

The primary verification work for the FSS data has included a study of the FSS calibration panel responses. Each of the calibration panel runs for each date were normalized with respect to sun angle (see equation 2.10-1) and plotted

$$CV_t = V_t / \cos \theta_t \qquad 2.10\text{-}1$$

where

V_t = FSS response to calibration panel at time t,

CV_t = Sun angle adjusted, FSS response to calibration panel at time t,

θ_t = solar zenith angle at time t, See Figures 2.10-1 and 2.10-2 for examples. Ideally the sun angle adjusted response curves would fall on the same curve. This assumes that the calibration panel is a Lambertian reflector, which is a good assumption down to 50° off normal. The situations which will cause the curves to be quite different are:

1) Data being collected on a cloudy day.
2) Not filling instrument field of view with the calibration panels.
3) Instrument instabilities.
4) Shadowing of the calibration panel.

It should be understood that a review of these curves does not necessarily give the whole story about all of the data collected on that day. However, a review of the plots does point out particular flightlines which the analyst may want to pay closer attention to. The values given with the plots (coefficients of variation) attempt to place some quantitative value to the variation of the curves so that dates can be compared. A summary of the average coefficients of variation is given in Table 2.10-1. The average coefficient of variation is <u>not</u> computed with band centers 1.425, 1.475, 1.825, 1.875, and 1.925 μm since they represent regions of strong water absorption.

The results in Table 2.10-1 indicate that there is significantly less variation on the adjusted calibration responses for the 1975-76 crop year than for the 1974-75 crop year. Some of the lower variation can be attributed to the shorter span in time between the first and last calibration panel observation for the 1975-76 crop year, since data were not collected over the extension flightlines.

Truck-Mounted Spectrometer Data

Information about the repeatability of the spectrometer measurements can be obtained using the gray panel data collected at the calibration location of the intensive test sites. The reflectance of the gray panels does not change appreciably through a year.

The variation in the measurements represents instrument instabilities. data collection and calibration variations, and panel reflectance variations. The panel reflectance variations can be due to either reflectance changes or differences due to an irregular ground surface (for those panels laid on the ground).

This information is being compiled and will be included in the verification report. Information is lacking, however, for the NASA/JSC interferometer (the FSAS system). The only data available to date is for gray panel 1. It is strongly recommended that the FSAS system collect measurements over the other four gray panels more frequently than has been the case in the past.

Spectrometer Data Correlation

The spectrometer data is being correlated using the gray panel data. A significant part of this data set is planned to be collected during mid-May at Finney County, Kansas - the sensor comparison experiments. The experiments planned will make it possible to compare the Purdue/LARS Exotech 20C and Exotech 100 systems and the NASA/JSC FSAS and FSS systems at reflectance levels from 5 to 55% with data collected at the same place and nearly the same time.

Table 2.10-1 Summary of FSS Calibration Panel Response Variations

Finney Co., Kansas		Williams Co., N. Dakota		Hand Co., So. Dak.	
Date	Ave. Coef. Variation*	Date	Ave. Coef. Variation	Date	Ave. Coef. Variation
		1974-75 Crop Year			
11/05/74	.13	6/5/75	.09		
3/20/75	.09	6/22	.08		
4/8	.09	7/10	.09		
5/14	.03	7/18	.06	Not	
5/21	.12	7/27	.02		
6/2	.04	8/5	.04	Applicable	
6/9	.10	8/15	.04		
6/17	.09	8/23	.06		
6/26	.04	9/1	.08		
7/6	.09				
		1975-76 Crop Year			
9/16/75	.05	5/13/76	.01	10/15/75	.06
10/3	.24	5/28	.01	10/30	-
10/21	.04	6/17	.01	11/5	.04
11/11	.03	6/25	.01	5/11/76	.03
3/18/76	.02	7/6	.03	6/1	.03
3/31	.05	7/20	.03	6/19	.05
4/18	.02	7/28	.03	7/8	.04
5/6	.03	8/9	.02	7/31	.03
6/12	.06	8/19	.08		
6/30	.07				
		1976-77 Crop Year			
9/28/76	.01			9/21/76	.02
10/15	.03				

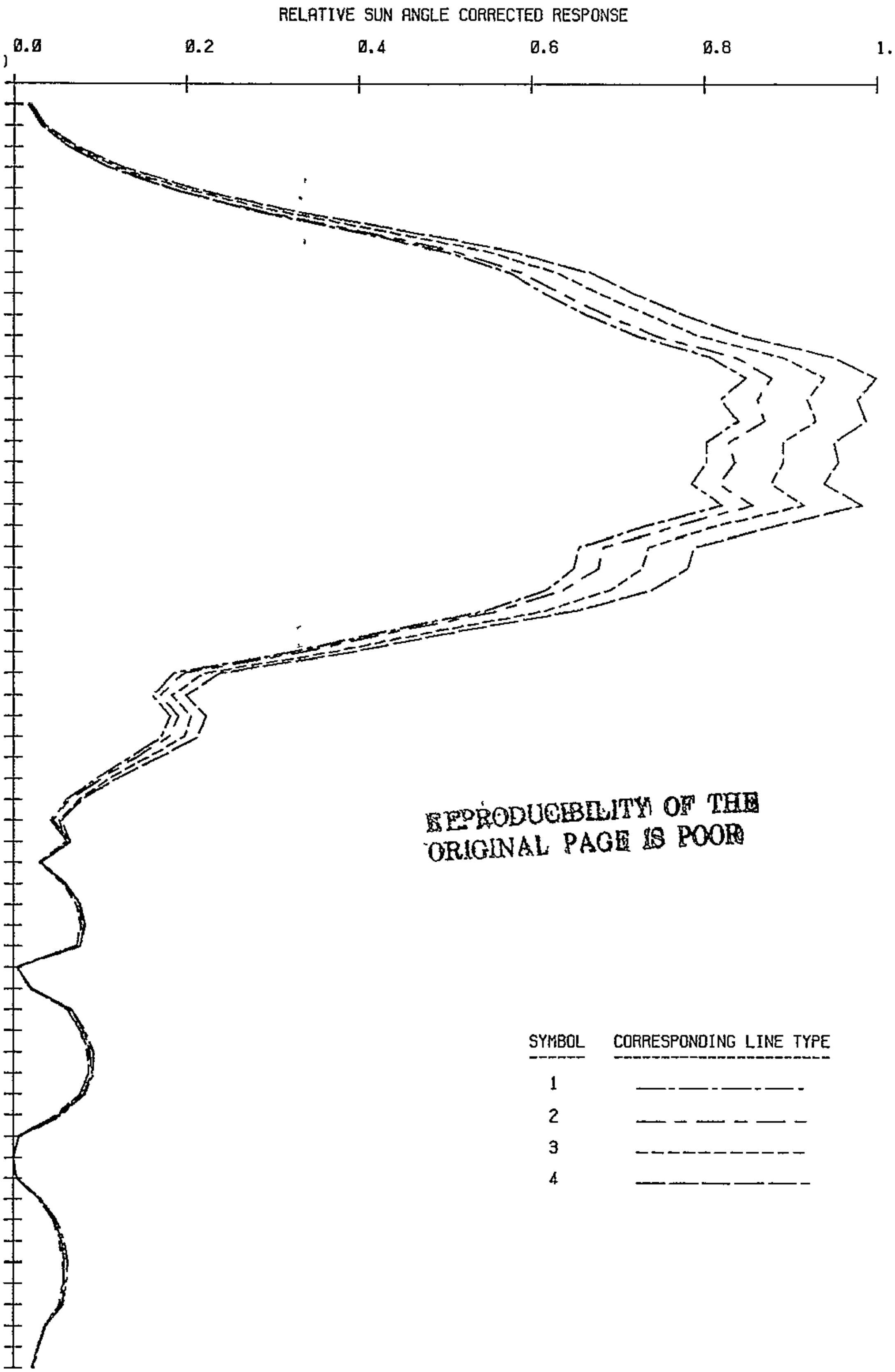
*Average coefficient of variation (standard deviation/mean) for all FSS bands except those at 1.425, 1.475, 1.825, 1.875, and 1.925 μm.

FIGURE 2.10-1
GRAPH OF SUN ANGLE CORRECTED CALIBRATION VALUES FOR 8 / 23 / 75
SITE WILLIAMS COUNTY N.D. LATITUDE 48.310N LONGITUDE 103.335W

SYMBOL	FLT. LINE	CAL TIME	IFOV	ZENITH	COSINE ZENITH
1	1	18.21.09	1.25	37.3	0.795
2	2	18.39.23	1.25	36.7	0.801
3	3	19.03.15	1.25	36.6	0.803
4	4	19.22.21	1.25	37.0	0.799

AVERAGE COEFFICIENT OF VARIATION (COEF. VAR.) IS .06

COEFFICIENT OF VARIATION	BAND CENTER (MICROMETERS)
0.07	0.410
0.06	0 430
0.06	0.450
0.07	0.470
0.07	0 490
0.07	0.510
0.07	0.530
0.07	0.550
0 07	0.570
0.07	0.590
0.07	0.610
0.07	0.630
0.07	0.650
0.07	0.670
0.08	0.690
0.07	0.710
0.08	0.730
0.08	0.750
0.08	0.770
0.08	0.790
0.08	0.810
0.08	0.830
0.08	0 850
0.08	0.870
0.08	0.890
0.08	0.910
0.09	0 930
0.11	0.950
0.09	0.970
0.09	0.990
0.10	1.010
0.10	1.030
0.10	1.050
0.11	1.070
0.12	1.090
0.03	1.125
0.02	1 175
0.02	1.225
0.03	1.275
0.03	1.325
0.03	1.375
0.03	1.425
0.04	1.475
0.04	1.525
0.04	1.575
0.03	1.625
0.03	1.675
0.03	1.725
0.04	1.775
0.09	1.825
0.82	1.875
0.04	1.925
0.03	1.975
0.04	2.025
0.04	2.075
0.03	2.125
0.03	2.175
0.03	2.225
0.03	2.275
0.03	2.325
0 02	2.375

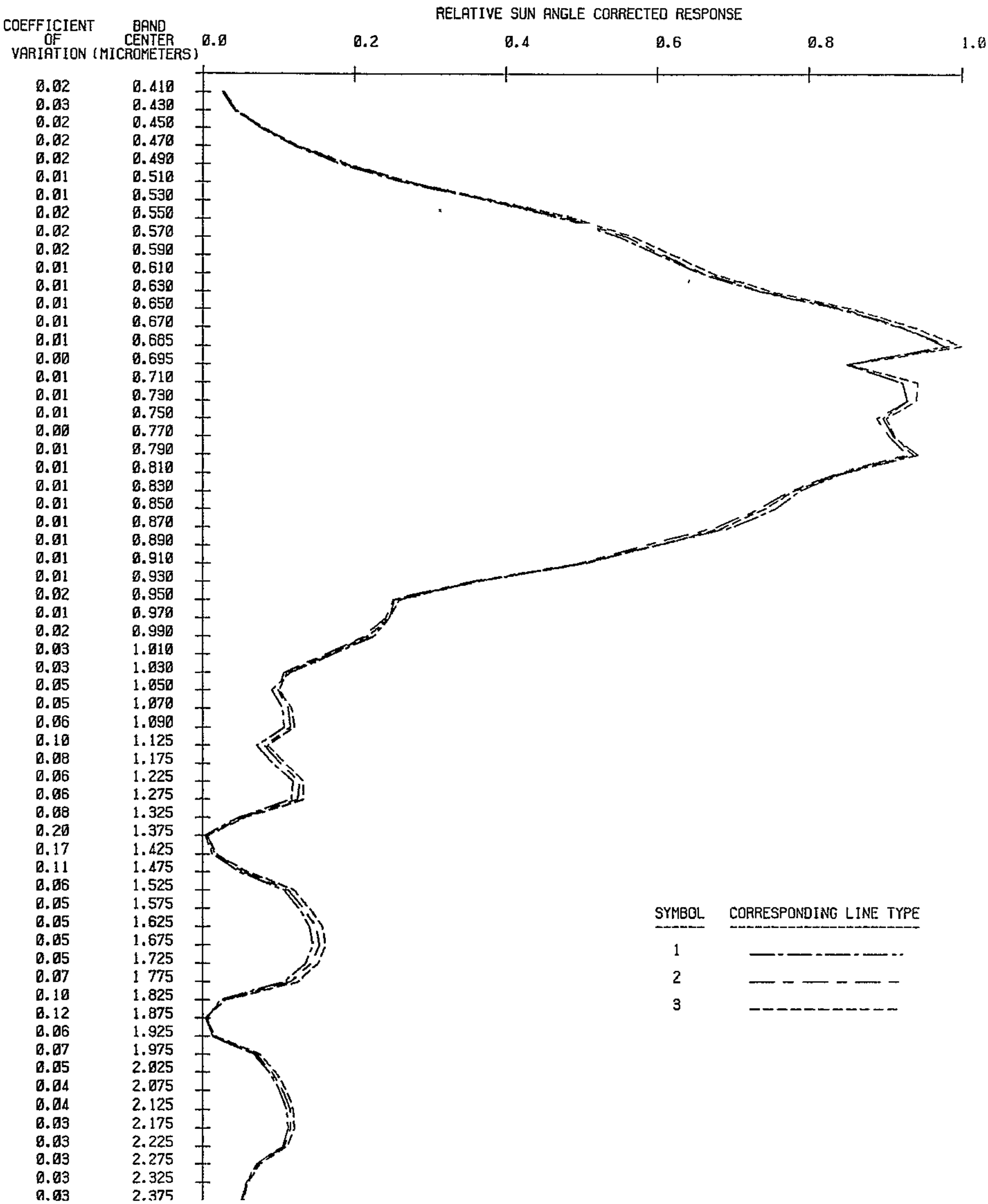


REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

FIGURE 2.10-2
GRAPH OF SUN ANGLE CORRECTED CALIBRATION VALUES FOR 5 / 6 / 76
SITE FINNEY CO. 2, KANSAS LATITUDE 38.148N LONGITUDE 100.665W

SYMBOL	FLT. LINE	CAL TIME	IFOV	ZENITH	COSINE ZENITH
1	8	14.57.51	1.25	52.8	0.604
2	9	15.20.54	1.25	48.4	0.664
3	10	15.42.44	1.25	44.2	0.717

AVERAGE COEFFICIENT OF VARIATION (COEF. VAR.) IS .03



2.11 Soil Classification and Survey

Spectral Relationships--Outdoor Exotech Experiment. The Exotech Model 20-C spectroradiometer will be used to measure the spectral reflectance from surface soils at the Purdue University Agronomy Farm during the week of May 9-13, 1977. An experiment has been set up to measure the effects of organic surface residue (corn stover) and soil moisture content on the reflectance of two soils differing greatly in surface soil color, organic matter content, and natural drainage.

Soils to be investigated are Chalmers silty clay loam, a dark colored soil developed under tall prairie grass, and Fincastle silt loam, a light colored soil developed under forest vegetation. The Chalmers soil is very poorly drained and has a dry Munsell color of 10YR4/1 in the surface horizon, and an organic matter content of about six percent. The Fincastle soil is moderately well drained and has a surface horizon with a dry Munsell color of 10YR6/2 and an organic matter content of about three percent. Chalmers soils occur in depressions on broad, gently undulating upland till plains on loam to light clay loam glacial till. Fincastle soils occur on broad, gently undulating divides on the border of the prairie uplands from a shallow covering of silt overlying glacial till. According to the USDA/SCS system of Soil Taxonomy (1), Chalmers silty clay loam is classified as a fine loamy, mixed, mesic, Aeric Ochraqualf.

Two plot sites have been selected, representing the two soils under investigation. On each site twelve plots measuring ten feet by ten feet each have been marked off, providing three replications of the treatment combinations. Plots have been aligned along the northern edge of the Agronomy Farm bulk fields to facilitate spectral measurements at an altitude of about 3 m above the soil surface.

Treatment combinations consist of two levels of moisture content along with two soil surface conditions: with and without organic residue. Soil moisture differences will be created by saturating the soil with water one day before reflectance measurements are taken on half the plots. The other half will remain at the field moisture level. Organic residue of corn stover will be applied at a rate of about one-half ton per acre to half the plots. This amount of corn residue is about twice that amount necessary to reduce erosion (2), while not obscuring the soil background to a large extent.

The four resulting treatment combinations for each soil are:

1) moist, bare soil

2) drier, bare soil

3) moist soil with corn stover residue

4) drier soil with corn stover residue

Surface roughness will be minimized to reduce shadow effects that may complicate reflectance measurements. While a rough surface promotes better infiltration, research indicates that surface residue is the more important factor in soil tillage considerations for water conservation (3).

Spectral measurements will be made with the Exotech Model 20-C over the spectral range from 0.5 to 2.38 μm. Using the 15° FOV mode, the soil surface area viewed at a height of 3 m will be circular with an 0.8 m diameter.

Readings will be taken on clear, cloud-free days as close to solar noon as possible to reduce sun angle effects. Measurements will be repeated on successive days to verify the repeatability of the spectral responses.

Surface soil samples of the upper one centimeter of soil collected at the time of the Exotech readings will be analyzed for moisture content, organic matter content, and other physical/chemical properties.

Expected results from this experiment are an increased understanding of the effects of soil organic matter, surface crop residue, and soil moisture content on spectral reflectance of surface soils. Possible "masking" effects of any one of these elements on any of the others will be observed and quantified. This should go a long way towards explaining the observed spectral differences of similar soils using Landsat data. Cooperative efforts with soil survey personnel will gain from a better understanding of the factors affecting soil reflectance in the field situation. The ability to identify soil conservation tillage practices from a remote position would permit soil managers to evaluate and monitor the extent of these practices.

Analysis of Landsat Data

Geometric correction and temporal overlay of three frames of Landsat data from Tippecanoe County, Indiana are being completed. The three frames being used are:

Date	Landsat ID
June 9, 1973	132115593
April 6, 1975	198715405
June 20, 1976	251515411

REFERENCES

1. Soil Survey Staff. 1975. Soil Taxonomy--a basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, U.S. Dept. of Ag., Agriculture Handbook No. 436, Washington, D.C.
2. Mannering, J. V., J. D. Meyer, and L. D. Meyer. 1963. The effect of various rates of surface mulch on infiltration and erosion. Soil Sci. Soc. Am. Proc. 27:84-86.
3. Griffith, D. R., J. V. Mannering, and W. C. Moldenhauer. 1977. Conservation tillage in the eastern corn belt. J. Soil and Water Conservation 32:20-28.

2.12 Improved Analysis Techniques for Multitemporal Data

INTRODUCTION

Objectives. The objectives of this task were to develop and test algorithms and procedures for analysis of multitemporal data sets; to evaluate the utility of classifiers of advanced design (such as perfield classifiers and layered classifiers) in contributing to effective multitemporal analysis; and to document and transfer effective techniques to NASA.

Approach. The most straightforward way to accomplish multitemporal analysis is to extend the "conventional" multivariate classification methodology to data sets formed by "stacking" or concatenating the multispectral data vectors from successive acquisitions over a given site. This presumes, of course, that the data sets are geometrically registered. This straightforward approach is attractive because of its apparent simplicity, and in some instances it produces excellent results, although at some computational cost due to the higher dimensionality of the data involved (computation is roughly proportional to the square of the total number of channels used for classification).

However, in addition to the computational cost, there are a number of compelling reasons to pursue alternative strategies for multitemporal analysis. All are directly or indirectly related to the relatively limited quantity of training data typically available in the face of the increased amount of training data actually needed for multitemporal analysis. Thus, the analysis techniques pursued under this task sought to minimize the need for training data while maximizing the performance gains derived from the multitemporal analysis.

The need for increased amounts of training data arises in many ways. To begin with, the joint effects of natural variability in the ground scene together with differential rates of change in the scene with the passage of time can result in an enormous profusion of "spectro-temporal" subclasses. Adequate training data must be found for each such subclass, and as the dimensionality of the data increases, the number of training data points needed per class also increases. Thus there is a two-fold effect.

The situation can become worse through the loss of reference data ("ground truth") due to various factors such as loss of the multispectral data at one or more of the acquisitions due to cloud cover or data system malfunction; and, in situations involving ground visitation, failure of the observer to make or accurately record sufficient observations at all specified sites.

Registration accuracy is also a factor in training sample availability. Training fields, which are often fairly small, must be treated as though they were even smaller in multitemporal data because of the increased edge effects due to registration errors.

In summary, although increased data dimensionality plus spectrotemporal variability in multitemporal data dictate a need for increased amounts of training data, there are many factors at work which tend to reduce the amount of training data actually available. Our approach to dealing with this dilemma is to use classification methods which permit "temporal decoupling", staged, rather than joint, use of multitemporal data, and thereby substantially reduce the demand for training data. The results obtained before termination of the project at mid-year had begun to demonstrate the effectiveness of this strategy.

Accomplishments. The accomplishments under this task, a six-month investigation terminated by the sponsor at the end of November, 1976, are summarized as follows.

Research was completed on techniques for registration of multitemporal data and a comprehensive technical report was prepared and delivered to

NASA [1]. Briefly, several registration methods were evaluated relative to their geometric accuracy capability. Also an investigation of the effects of relative geometric distortion on registration accuracy was conducted.

Four multitemporal data sets were assembled, including registered LANDSAT data and comprehensive reference data. All were agriculturally oriented, one from the earlier CITARS project and three from LACIE. More information on these data sets is contained in the quarterly report for the period September 1, 1976 to November 30, 1976. That report also contains the experimental procedure to have been pursued in evaluating the proposed multitemporal analysis strategies.

Two methods of multistage classification for multitemporal analysis were proposed: the Layered Classifier or decision tree classifier developed earlier [2,3], and an extension of the maximum likelihood classifier which we have dubbed the Cascade Classifier. The latter is described more fully later in this report.

Due to the premature termination of this task, it was not possible to develop or evaluate these approaches comprehensively as had been proposed. The preliminary results obtained, however, indicate that both approaches have much to offer in the multitemporal domain. These results were obtained through a student project in the School of Electrical Engineering at Purdue University.

Conclusions. Despite the rather apparent need and potential payoff, a comprehensive investigation of multitemporal analysis strategies has yet to be completed. The "stacked vector" method of analyzing multitemporal data has definite shortcomings. Multistage methods clearly have promise, based on actual analysis results obtained to date.

DESCRIPTION OF THE RESEARCH

Multitemporal Image Registration. Proposed research has been completed on techniques for registration of multitemporal multispectral scanner imagery (see reference [1]). Several preprocessing techniques were evaluated to determine what methods provided the maximum improvement in image registration accuracy. It was determined that magnitude-of-the-gradient enhancement performed best. Several correlation measures were also evaluated, and although the correlation coefficient gave the best performance, the absolute difference method gave almost as good performance with much less computational cost. Thus this method is recommended.

Several other aspects of the registration problem were considered in this work. A theoretical method for estimating the variance of the registration error was developed. This result was used to derive a correlator which optimizes performance. An investigation of the effects of relative geometric distortion on registration accuracy was conducted using various signal and noise assumptions. Finally the statistical properties of temporal changes in LANDSAT data were evaluated. These studies support the advancement of the state of the art in image registration and are a part of a growing body of knowledge related to the image registration problem.

The Layered Classifier. Documentation of the basic Layered Classifier program, which implements any user-specified layered decision logic, was essentially completed. A user-oriented control card summary is available and flow charts for the software have been drafted. This LARSYS-compatible program is available to any user of the Purdue/LARS remote terminal system. For more information, see Section 2.1 of [3].

The Cascade Classifier. The Cascade Classifier is a maximum likelihood classifier reformulated and extended to permit "temporal decoupling" or time-staged analysis. It is a very versatile classifier model, applicable to multitype data (e.g., from multiple sources) as well as multitemporal.

Briefly, the method is derived for the bitemporal case by assuming a risk function of the form

$$L_{X_1,X_2}(j) = \sum_{i=1}^{m} \lambda(i,j)\ p(\omega_{2i})|X_1,X_2)$$

where ω_{2i} stands for class i at time 2. $L_{X_1,X_2}(j)$ is the average loss incurred by classifying the point characterized by $X_1 = X(t_1)$ and $X_2 = X(t_2)$ into class j. The Bayes' strategy is to minimize L; the maximum likelihood strategy develops from taking the loss function $\lambda(i,j)$ to be the familiar 0-1 loss function.

Pursuing this development leads to a discriminant function of the form

$$d = \sum_{\omega_1} p(X_1,X_2|\omega_1,\omega_2)\ p(\omega_2|\omega_1)\ p(\omega_1)$$

where all subscripts refer to time of acquisition. Notice that $p(\omega_2|\omega_1)$ can be interpreted as a transition probability.

By making certain approximations (which are exact under proper temporal situations), this discriminant function can be written as

$$d = \sum_{\omega_1} p(X_1|\omega_1)\ p(X_2|\omega_2)\ p(\omega_2|\omega_1)\ p(\omega_1)$$

and it is from this expression that the term "Cascade Classifier" arises. This expression implies a classifier model which is shown schematically on the following page (Figure 1).

There are two advantages to this form of the classifier model, both related to "temporal decoupling". First, the required density functions

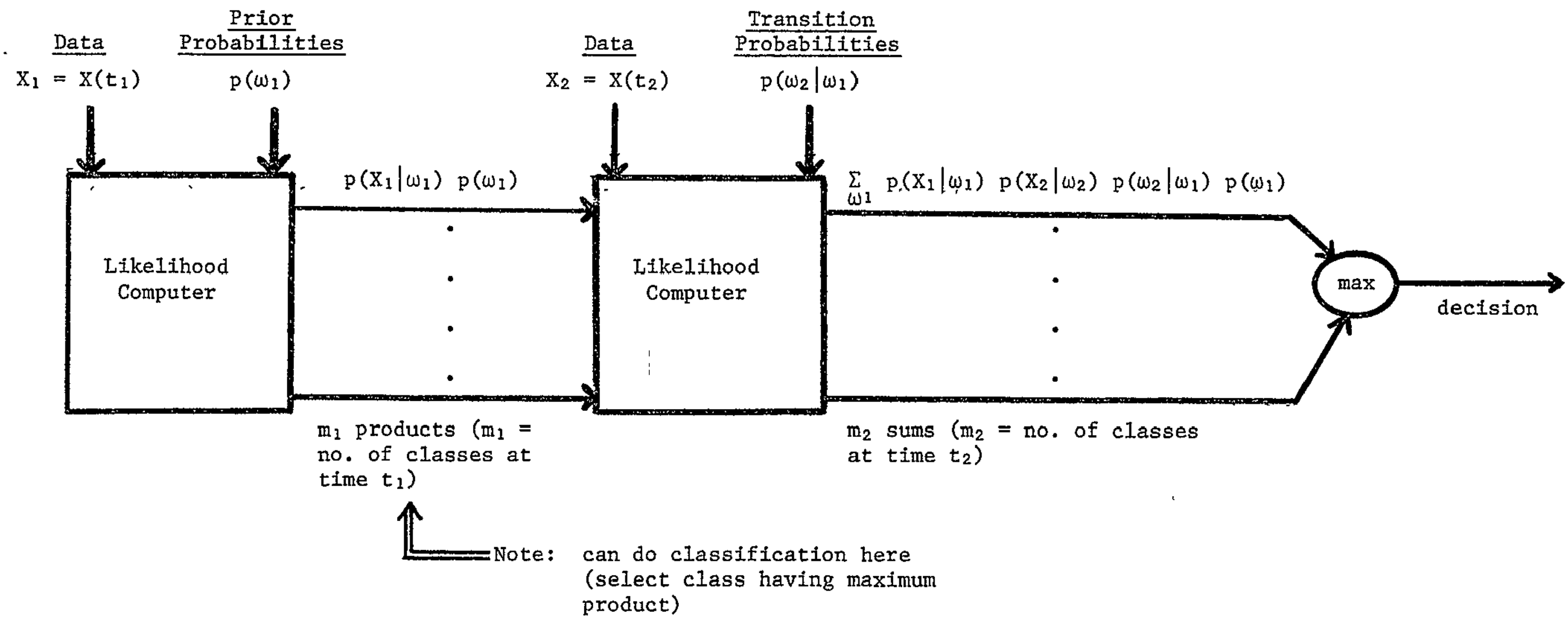


Figure 2.12-1. The Cascade Classifier

are n_1- and n_2-dimensional, rather than being n_1+n_2-dimensional as in the "stacked vector" case. Second, this model allows classification to be performed at time 1 and the statistical results passed along to subsequent analysis at time 2. Thus optimal use can be made of the data as it becomes available, rather than waiting until after the last acquisition. This has implications for computational efficiency as well.

This model is easily generalized to more than two stages or times; we simply "cascade" similar stages.

Software implementing this multistage classifier has been developed.

Experimental Results. Comparative analyses were performed for the Fayette County and Grant County test sites.

The Fayette County, Illinois, test site was classified into corn, soybeans, wheat, and other. The Layered Classifier was designed to use t_2 data to resolve uncertainties resulting from classification of t_1 data. The Cascade Classifier was designed using highly simplified assumptions about the prior probabilities and transition probabilities. The results were as follows:

t_1 unitemporal (June 29, 1973)	68% correct overall
t_2 unitemporal (July 17, 1973)	72% correct overall
Layered Classifier	82% correct overall
Cascade Classifier	84% correct overall

The Grant County, Kansas, test site was classified into alfalfa, corn, fallow, pasture, wheat. The same design strategies were used as in the Fayette County case. The spectral discrimination problem was clearly much more difficult (notice that the unitemporal performance is considerably below that of the Fayette County case). The results were as follows:

t_1 unitemporal (May 9, 1974)	62% correct overall
t_2 unitemporal (July 20, 1974)	55% correct overall
Layered Classifier	68% correct overall
Cascade Classifier	64% correct overall

In this case, the Cascade Classifier was apparently much more sensitive to the simplified assumptions used for the prior probabilities and transition probabilities.

In neither of the above cases was there sufficient training data available to permit multitemporal analysis by the "stacked vector" approach.

Conclusions and Recommendations. Many questions remain to be answered with respect to how to best make use of the information contained in the temporal dimension when multitemporal data is available. The "stacked vector" analysis approach is the most straightforward to apply, but though successful in some instances, it suffers some severe disadvantages when the availability of training data is relatively limited. It is also computationally very expensive unless subsets of the available multitemporal channels are selected.

Multistage analysis, using methods such as the Layered Classifier and the Cascade Classifier, ameliorate many of the difficulties encountered with the "stacked vector" approach. The dimensionality of each decision is minimized, and this reduces both the computation and the amount of training data required. Experimental results obtained using these classifiers demonstrate that further investigation of this staged approach to multitemporal analysis is warranted. Pursuit of this research is strongly recommended.

ACKNOWLEDGEMENTS

The project scientist for this task was Dr. Philip H. Swain, School of Electrical Engineering, Purdue University. Major contributions to the research and development were made by Jeanne Etheridge, Systems Programmer at LARS, and by Carlos Pomalaza, graduate student in the School of Electrical Engineering.

REFERENCES

1. Svedlow, M.C., C.D. McGillem, and P.E. Anuta, "Analytical and Experimental Design and Analysis of an Optimal Processor for Image Registration," LARS Information Note 090776, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana 47907, September 1976 (178 pages).

2. Wu, C.L., D.A. Landgrebe, and P.H. Swain, "The Decision Tree Approach to Classification," LARS Information Note 090174, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana 47907, September 1974 (194 pages).

3. Final Report on NASA Contract NAS9-14016, D.A. Landgrebe, Principal Investigator, June 1, 1975 to May 31, 1976, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana 47907.

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