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Final Report

Processing Techniques Development

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16. Abstract

Work reported in this volume includes implementation of the LIST (Label Identification by Statistical Tabulation) method under the Technology Development subtask; the support of the NASA/JSC remote terminal, development of instructional materials, and planning for future technique interchange between NASA/JSC and Purdue/LARS under the Technology Interchange System Development subtask; and, under the Scanner System Parameter Selection subtask, evaluation of a classification error prediction algorithm and development of scanner system models by information theoretic and Karhunen-Loeve approaches.

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III. Processing Techniques Development.

This task is divided into two subtasks: Technology Evaluation and Development and Scanner System Parameter Selection. A portion of the Technology Evaluation and Development subtask which concerns the documentation and evaluation of the unsupervised ECHO (Extraction and Classification of Homogeneous Objects) is published in a separate volume so that analysts interested in using that algorithm may obtain its documentation and evaluation without acquiring excess pages. The remainder of the Processing Techniques Development task is reported in this volume.

The Technology Evaluation and Development subtask is comprised of two major portions: Technology Development and Technology Interchange System Development. The Technology Development portion has been concerned with the implementation and evaluation of the LIST (Label Identification from Statistical Tabulation) approach to image labelling and the completion of the evaluation of the ECHO (Extraction and Classification of Homogeneous Objects) classifiers which was begun in FY77. The Technology Interchange System Development portion of the Technology Evaluation and Development subtask has supported the JSC 2780 terminal, the conversion of JSC software to the LARS system, the development of the ECHO Analysis Case Study and Data 100 instructional materials, and the planning of a short course to increase technique interchange between NASA/JSC and Purdue/LARS.

The Scanner System Parameter Selection study has addressed the problem of evaluating proposed scanner system designs by developing models for scanner systems and methods for evaluating the classification error of a scanner system for a given remote sensing objective.

A-1. Technology Development.

I. Work Accomplished:

Work on Technology Development during the contract period concentrated on:

- studying the characteristics of the labelling procedure called LIST (Label Identification from Statistical Evaluation);
- bringing together a data set for the study and evaluation of this labelling procedure;
- writing and debugging programs supporting the LIST investigation; and
- formulating the integration of the LIST labelling procedure and recent developments in remote sensing technology.

During this quarter, we have started to study the characteristics of the dot labelling procedure called LIST (Label Identification from Statistical Tabulation) developed by a joint SRT (UCB and ERIM)/LEC effort. This statistical approach for estimating dot labels is based in the answers of an analyst to a list of questions, with the help of associated ancillary data. The answers are used in a linear discriminant analysis for finding the corresponding label. The method has already been tried at JSC, with some encouraging results. With the information at our disposition we are initiating a similar sequence of procedures in order to evaluate the method and find some possible modifications and alternatives. In addition to the general objectives of the LIST Method [1] additional goals for this work are:

- Make the procedures as machine oriented as possible with the idea of obtaining a partially (or in the best case totally) computer implemented technique.
- Possibly modify the actual set of questions by restating them in a more quantitative form and/or by the addition of new questions. This may be done with the idea of improving the performance or for obtaining objective (a).
- Study alternative methods of analysis as well as the linear discriminant approach.

With these objectives in mind the present set of questions were examined.

Although at the present time all the material necessary for completing all the questions is not available at Purdue/LARS, some general comments can be made regarding the machine adaptability of the LIST questions.

- Segment Questions from Imagery: Most of the questions in this set have to be answered by a human analyst, making the use of an automatic procedure difficult.

- Cropping Practices: This set of questions requires some ancillary data, such as nominal crop calendar and percentage of crops, and again the intervention of the human analyst is decisive.

- Meteorological Data: In answering these questions, the analyst must rely primarily on the met summary. In this case most of the answers can be quantified, making them more suitable for machine processing.

- Pixel Specific Questions: This set of questions seems to be the most important in order to label a specific dot. The analyst in this case has to use his knowledge and experience, including a familiarity with different kinds of aids such as spectral plots, trajection plots, green numbers, Kraus product, and crop statistical data. Some of the questions can be easily quantified but there are others whose answers depend a great deal on the analyst and cannot be objectively quantified. The knowledge and experience of the analyst can be decisive in several cases so that the idea of a totally automatic procedure may not be possible. As a result of this preliminary evaluation of the LIST questions, an attempt is being made to restate some of the questions in a more quantitative way and to supplement some subjective questions with more objective measures in order to obtain at least a partially automatic procedure.

Seven LACIE segments in Kansas in the 1976 crop year have been selected as the basis for the study of this procedure. These segments (1851, 1856, 1857, 1860, 1865, 1866, and 1889) were chosen based on the availability at LARS of the corresponding full-frame imagery and true dot labels. The LIST method has been applied to segments 1857 and 1865. Several problems have appeared and are discussed below.

Programs for computing green numbers and trajectory plots have been implemented. Additional forms of displaying the digital information are being investigated in order to aid the analyst in his labelling decisions.

After some review of available algorithms for discriminant analysis, it seems that the one available in the SPSS statistical package is, at least as a starting point, the most suitable, especially as a stepwise procedure for selecting the most important features or variables is possible. However, at a later stage, the use of a special purpose algorithm for carrying out the classification may be better.

II. Problems Encountered

The chief problem encountered to date in implementing the LIST method has been the difficulty in acquiring the ancillary information for the seven segments being studied in Kansas. The following information forms the basis for some questions in the LIST method as it is presently formulated, and is not currently available at LARS in the form it has at JSC:

a. percentage of each crop in county
b. nominal crop calendar
c. expected normal yield for a segment
d. DU and DO areas for the segment
e. Kraus products
f. crop calendar adjustment information
g. green number/biostage chart.
h. examples of small grains trajectory plots and spectral development patterns
i. crop statistical data.

That information available to the LACIE analyst-interpreters at JSC (items a, b, c, f, and i) is being sent to LARS from JSC but has not yet arrived. The DV and DO areas for each segment can be estimated from the PFC's presently available to us. Duplicates of the Kraus products will be requested, after the other information has arrived at LARS and has been integrated into the LIST study. It is our understanding that green number/biostage charts and examples of small grains trajectory plots and spectral development patterns are not currently part of the analyst aids supplied to the AI. If additional sets exist or are under development, copies would be of great assistance in this project.

III. References

1. "Plan for Defining Dot Labelling Procedures for Procedure 1, The LIST Method", March 7, 1977.

A-2. Technology Interchange System Development.

I. Work Accomplished

Work on technology interchange system development during the contract period concentrated in the following areas:

- Software Conversion Support
- Tape Copy Software Plan
- Support of the JSC 2780 terminal
- ECHO Analysis Case Study
- Data 100 system instructional materials
- LARS System extended user facilities short course plan
- Technique Interchange plan

During this contract period the concept of a Purdue terminal located at the Earth Observation Division of NASA/JSC has matured. This maturing process has changed the installation date of the Data 100 terminal from that envisioned in the implementation plan approved in June. As a result of these actions the terminals and the Purdue personnel supporting them are in a much better position to serve the needs of the Earth Observation Division. Another result is that some of the subtasks included in the implementation plan have received greater attention than originally envisioned and others have been delayed. The subtasks receiving greater attention were the software conversion support and the support of the JSC 2780 terminal. The subtasks which have been delayed are the tape copy software plan, Data-100 installation, the tape copy software implementation, and the Data-100 installation evaluation.

During the past six months the communication between personnel at LARS and the personnel at JSC with respect to the Purdue terminal has increased significantly. This communication has been centered around the software aspects of the terminal especially in support of the computer needs at JSC. Several visits have been made by Purdue personnel to JSC to investigate methods of providing better service and to relate specific capabilities of the Purdue hardware and software to JSC personnel. Education and consulting details have been worked out to make the transfer of software by JSC personnel to the Purdue computer as effective and efficient as resources permit. A visit by Lockheed personnel to Purdue is planned for early November for the same purpose.

In addition to the exchange of information in person, there have been frequent communications between personnel both via written documentation and telephone. As a result, there has been a change in computer systems at Purdue which has enhanced the terminal's capabilities at JSC. In addition the plans for the installation of the Data-100 are well understood by both Purdue and JSC personnel.

Purdue support of the JSC 2780 terminal has also been increased over the project period. The services provided for the first five months were approximately $29,000 as compared to the $24,000 budgeted for June through November. This increase in services has primarily supported the software conversion subtask.

With the announcement of a specific date for the Data-100 installation, a tape copy software plan is receiving attention. It is expected that the plan will be completed by November 30 for approval by the JSC personnel. The hardware installation and tape copy software implementation are tasks which will be completed during the next contract year.

A case study on the use of the ECHO classifier (Extraction and Classification of Homogeneous Objects) for analyzing multispectral scanner data has been completed. The materials prepared for the case study include a case study document LARS Publication 090177 "A Case Study Using ECHO for Analysis of Multispectral Scanner Data," a set of instructor notes, a set of reference data consisting of maps and aerial photographs and a sample analysis. The case study document introduces the ECHO processing function and typical steps in the analysis of remotely-sensed data using ECHO are illustrated through discussion, an illustrative example and exercises. The instructor notes, reference data and sample analysis serve as aids to individuals wishing to carry out the analysis steps themselves.

A new unit of the LARSYS Educational Package, "Data 100 Remote Terminal: A Hands-On Experience", has been prepared. This unit of the educational package consists of a set of student notes, accompanying audio tape, card decks and instructor notes. These materials were prepared in anticipation of a decision by JSC to upgrade their remote terminal through installation of a Data 100 system. Availability of this new unit of the educational package will allow for immediate training and access to the LARS computation facilities by means of the Data 100 terminal.

An outline of a short course covering topics designed to introduce JSC terminal users to the extended user facilities of the LARS computer facility has been prepared (see Appendix A-1). An earlier version of this outline was presented to JSC personnel at the quarterly program review held in September 1977. Since that time the outline has been revised to reflect comments received during the review and work has been initiated in detailing those portions of the course identified as being of keen interest to JSC personnel. As a result of an early November meeting with Tom Minter of LEC, the division of this short course into several one or two day seminars with different emphases has been proposed as a more effective way of promoting technique interchange. Also proposed were two or more seminars to be given by JSC or LEC personnel at LARS to inform and aid LARS personnel in using the software presently being converted to the LARS system.

A two-part plan dealing with the interchange of technical information, techniques and procedures between NASA/JSC and Purdue/LARS has been prepared. Part I, dealing with specific retraining needs that would result from an upgrade of the JSC/LARS remote terminal, was discussed at the September quarterly program review. Part II deals with the interchange of technical ideas and techniques from a more general viewpoint. It seeks to identify features and conditions common to any technical interchange and suggests an approach for facilitating and managing technique interchange. Parts I and II of this plan appear as appendices A-2 and A-3 of this report.

II. Problems Encountered.

Delay in the Data 100 installation decision has made it necessary to carry out work under this task in more of a contingency mode of operation rather than working towards specific technique interchange goals. While this has made it difficult to follow the implementation plan schedule it has resulted in the development of a broader view of the problem. The net effect, we believe, will improve the longer range objectives of the technology interchange system development effort.

Appendix A-1. Short Course on Purdue/LARS User Facilities Available via a Data 100 Remote Terminal

Day 1 A.M.

I. Introduction
   Course Outline, Materials

II. What do I have to do before I can use the LARS system?
   Computer ID's - Passwords - whom to contact

III. Data 100 demonstration. Exercise 1 - Data 100 Hands-on operation.

Day 1 P.M.

IV. Remote Terminal Procedures
   Responsible personnel
   How to dial up (when necessary)
   Login procedure

V. Overview of LARS computer system
   Machine type
   storage capabilities
   operating system
   available environments
   virtual machines
   CP command Q V
   system flowchart

VI. VM370 CP Commands
   Assessing System
   Controlling files

Day 2 A.M.

I. Review CMS editing

II. Overview EXECS

Exercise: Edit in BATCH EXEC

Day 2 P.M.

III. CMS utility functions

IV. Review Classifypoints processor

A. Subroutines - system manual
B. Loading and execution

V. Modify classifypoints to become minimum distance classifier

A. Coding
B. Creating the module
C. Placing the module in the appropriate place

Exercise: go to terminal and get copy of appropriate fortran coding and edit in coding changes.

Day 3 A.M.

Exercise: After code is modified - create the module

I. Abstracts
A) understanding what is happening
B) knowledge of how to use in other programs

II. Review new program that plots spectral trajectories

Exercise: Edit in *TRAJECT coding set up to run

Day 3 P.M.

Simulation Exercise: adding CGROUP to SEPARABILITY
A) Coding
B) Establishing Proper Loading
C) Executing

Day 4 A.M.

Group Exercise: How to connect BIPLOT and SEIGEN to get transformed plots

I. Recoding required
Change Appropriate part of SEIGEN to callable subroutine
Change BIPLOT to call the new subroutine

II. Loading Necessary - EXEC file

Exercise: various people edit in various changes

Day 4 P.M.

III. With T.I. in classroom - as a group
try loading - debug as necessary

When complete

Try EXECUTION - debug as necessary

Day 5 A.M.

I. Continue debugging if necessary

II. Consultation time - what you want to do and the best
way to do it

Day 5 P.M.

III. Course Summary
A) Review systems, LARSYS standards manuals

IV. Other Documentation
A. 370 Materials: VM370 and CMS 370
B. Scanlines

Technique Interchange Plan-Part I*

John C. Lindenlaub
Purdue/LARS
September 1, 1977

Outlined in this document, the first of a two-part technique interchange plan, are plans to meet the specific retraining needs that would result from an upgrade of the JSC/LARS remote terminal from its present IBM 2780 configuration to a Data 100 system and to provide training and experience to JSC personnel in using the LARS computer system at a level considerably beyond that covered in the LARSYS Educational Package. Included in the plan are provisions for training personnel in the use of the new hardware configuration, presentation of an ECHO analysis case study, a lecture/workshop series on system capabilities, and suggested procedures and requirements to make the field measurements data base accessible to a larger group of users.

By selecting different portions of the plan the level of technique interchange can range from learning how to operate the new equipment, to a management overview of system capabilities, to indepth study and experience in algorithm implementation.

A subsequent document, Technique Interchange Plan-Part II, will address the more general problem of exchanging any technique between JSC and LARS or LARS and JSC using the remote terminal system.

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*Prepared under NASA contract NAS9-14970

New Hardware Configuration

To handle the retraining requirements which will result from the installation of new remote terminal hardware equipment at JSC, it is proposed to replace Units III and IV of the LARSYS Educational Package, with materials entitled Unit III - Demonstration of the Data 100 Remote Terminal and Unit IV - The Data 100 Remote Terminal, a Hands-On Experience. These new materials will be modeled after the existing units III and IV of the LARSYS Educational Package.

There are several reasons for this approach. First the manpower requirements to modify these units of the educational package are not large, in fact draft versions of these materials already exist. Second, installation of new equipment will impact all present as well as future users and training materials patterned after the LARSYS Educational Package materials will provide a convenient mechanism for training present as well as future users of the system. It is also expected that training of people to utilize the remote terminal will be spread out over a considerable time duration and it is advantageous to have training materials that can be used by individual students and require a minimum of effort on the part of training personnel. Furthermore, upgrading of the LARSYS Educational Package materials to match the remote terminal hardware will preserve the entire LARSYS Educational Package and make it available to new personnel.

ECHO Classification Procedures

A case study has been prepared to illustrate ECHO analysis techniques. It is proposed to conduct a series of workshops using the case study materials to train a group of JSC personnel in ECHO analysis techniques. The ECHO case study will be used as part of a more comprehensive series of lectures and workshops dealing with use of the remote terminal system. This is discussed in the next section.

A case study detailing ECHO analysis techniques was prepared because of the newness for the technology and the relative complexity of the algorithm. Use of the case study materials in a series of lecture workshops instead of on an individual basis is suggested for reasons of economy of scale. It is also expected that further experimentation and development of ECHO analysis procedures will be undertaken in the future and the case study will provide a solid introduction to this analysis technique.

Efficient system utilization

A short course for users of the LARS computer system at JSC has been planned. The course is one week in duration. Composed of lecture and workshop sessions this course is designed to introduce the participants to system capabilities such as CMS, experimental and developmental LARSYS programs, and procedures for placing new programs on the system.

The short course format is particularly well suited because system capabilities are documented in a variety of reference sources. An experienced analyst, serving as the short course instructor, can guide participants through these sources and adapt the training to meet the requirements of different participants in the course who wish to achieve different levels of capability or who wish to have different portions of the course emphasized.

An outline of this proposed short course is shown in appendix A. This outline is intended to serve as a point of departure for designing the course and it is anticipated and hoped that a JSC terminal user or remote terminal site expert would be available to contribute to the finalization of the course design and work jointly with the LARS staff member in presenting the course.

Access to field measurement data

Suggested procedures for obtaining better access to field measurements data by JSC personnel is significantly different than procedures suggested in the sections above. If a requirement exists on the part of JSC to have better access to field measurements data it is suggested that the individuals needing access to this data plan to spend a one to two week period at LARS working with LARS personnel who are familiar with the software system and the data analysis and collection techniques. Following a reasonable interval of, say, four to six weeks, a member of the LARS staff would plan to spend three to five days at JSC working with personnel on the remote terminal system accessing and analyzing field measurements data.

This intensive one-on-one instruction is suggested in this case because of the limited amount of documentation available on the EXOSYS system and the relatively dynamic nature of the software system. It would require considerably more effort to prepare suitable documentation if a larger number of JSC personnel were to be trained in this area.

Discussion

The short course outlined in Appendix A provides the framework for satisfying a number of technique interchange needs. Participation in the morning session of Day One is all that is required for individuals desiring merely to learn "what new buttons have to be pushed" to operate the Data 100 Remote Terminal. Individuals interested in a "management overview" of the remote terminal system can obtain this information by participating in the afternoon session of the first day of the course. Individuals wishing to learn how to use the system efficiently along with programs which are presently on the system would participate in the entire short course. Intermingling of the lecture presentations and computer exercises helps provide necessary experience and reinforcement of the ideas presented in the lectures. The series of exercises suggested in the outline of Appendix A are geared towards presentation of ECHO analysis techniques. Other exercises could be substituted for individuals wishing to emphasize other aspects of the system. It is suggested that a LARS data analyst and a JSC site expert jointly contribute to the planning and teaching of the course. This would increase the likelihood of having sets of examples and lecture presentations which are particularly valuable to course participants.

NASA Furnished Items

In order to conduct the proposed course NASA must provide space (conference room or class room) and be able to dedicate the JSC remote terminal for at least four hours a day for training purposes. Table or desk space for the LARS analyst instructor in or near the terminal area would also be desireable.

Two man-weeks effort of a JSC computer system specialist or remote terminal site expert would significantly improve the training course. One week would be spent in joint planning with LARS to guarantee that the course content and computer exercises are well matched to JSC needs. The second man-week would be used in assisting with the course presentation and computer exercises.

Scheduling

LARS requires a minimum of 30 days advance notice of the dates the training course is desired and the number of persons expected to participate.

Appendix A

Beyond LARSYS: CMS, LARSYSXP, LARSYDV
Proposed Short Course for Users of the LARS Computer System at JSC

Day 1 A.M.

I. Introduction
Course Outline, Materials

II. What do I have to do before I can use the LARS system?
Computer ID's - Passwords - who to contact

III. Data 100 demonstration. Exercise 1 - Data 100 Hands-on operation.

Day 1 P.M.

IV. Remote Terminal Procedures
Responsible personnel
How to dial up (when necessary)
Login procedure

V. Overview of LARS computer system
Machine type
storage capabilities
operating system
available environments
virtual machines
CP command Q V
system flowchart

VI. Review general analysis steps

VII. Overview of Short Course
examples of how the system can be used more efficiently and discussion of advantages
use of operating system
assessing system (query)
control of files (remote, purge, close, set, xfer)
use of CMS for control cards, submitting batch jobs
new or revised LARSYS functions
use of CMS for altering virtual machine
use of CMS for altering or establishing programs

Day 2 A.M.

VIII.CMS - editting

IX. Control Cards
where to get listings
review PICTUREPRINT control cards
class write control cards needed

Exercise 2. Using CMS create a disk file containing all the cards needed to produce a grayscale image from PICTUREPRINT

Day 2 P.M.

X. Other CMS functions

XI. Batch Machines
Exercise 3. Add necessary batch control cards to PICTUREPRINT file and submit the batch job from the terminal

Day 3 A.M.

Exercise 4. Assemble grayscale and pick candidate training areas.

XII. Review cluster control cards (DV or XP - IDNAME)

Exercise 5. Using CMS create cluster control card file and submit to LARSYS on line

Exercise 6. Identify cluster classes

Day 3 P.M.

XIII. More analysis
merging statistic files (options)
checking class separability

Exercise 7. Submit MERGE and SEPARABILITY jobs via card reader to batch machine

Exercise 8. Use separability output to decide how classes should be combined

Day 4 A.M.

XIV. How to check validity of decisions
rerun separability
use of BIPLOT and SCATTERPLOT

Exercise 9. Rerun MERGE and SEPARABILITY if ok run BIPLOT and SCATTERPLOT to evaluate further

Day 4 P.M.

XV. ECHO vs CLASSIFYPOINTS
ECHO control cards

Exercise 10. Run ECHO classification and PRINTRESULTS

Day 5 A.M.

XVI. Review results

XVII. Other output products
Varian
Meade

XVIII. Other experimental or developmental LARSYS processors

XIX. Documentation
LARSYS users manual
LARS computer users guide
Scanlines

Day 5 P.M. or worked in as time permits

XX. CMS - programming EXECS

XXI. LARSYS system manual

XXII. Abstracts

XXIII. You can modify LARSYS programs or write new ones of your own.

Technique Interchange Plan-Part II*

John C. Lindenlaub

Purdue/LARS

November 15, 1977

This is the second part of a two-part document dealing with the interchange of technical information, techniques and procedures between NASA/JSC and Purdue/LARS. The first part of the document, dated September 1, 1977, dealt with specific retraining needs that would result from an upgrade of the JSC/LARS remote terminal.

This part of the plan deals with the interchange of technical ideas and techniques from a more general viewpoint. It seeks to identify features and conditions common to any technical interchange and suggests an approach for facilitating and managing technique interchange.

The plan described here is an outgrowth of the experience gained from the Remote Terminal Experiment [1], several years of experience with 2780 terminal capability at JSC and is predicated on the assumption that JSC will upgrade their terminal hardware and that the JSC/LARS terminal will continue to be the prime motivation and facility for carrying on technique interchange activities.

Examples of the kinds of technical interchanges under consideration are: 1) transfer of Procedure I analysis techniques from JSC to LARS, 2) transfer of capability to access and analyze field measurements data from LARS to JSC, 3) transfer of techniques for modifying or adding algorithms to the set of experimental LARSYS programs from LARS to JSC, and 4) transfer of specific data analysis programs (such as clustering algorithm) from JSC to LARS.

Fundamental Parameters

There are a number of parameters which govern the technique interchange process which must be taken into account when planning procedures for the interchange of techniques between two technical organizations. These parameters are:

- number of persons to receive technique
- present state of technology
- time constraints

*Prepared under NASA contract NAS9-14970

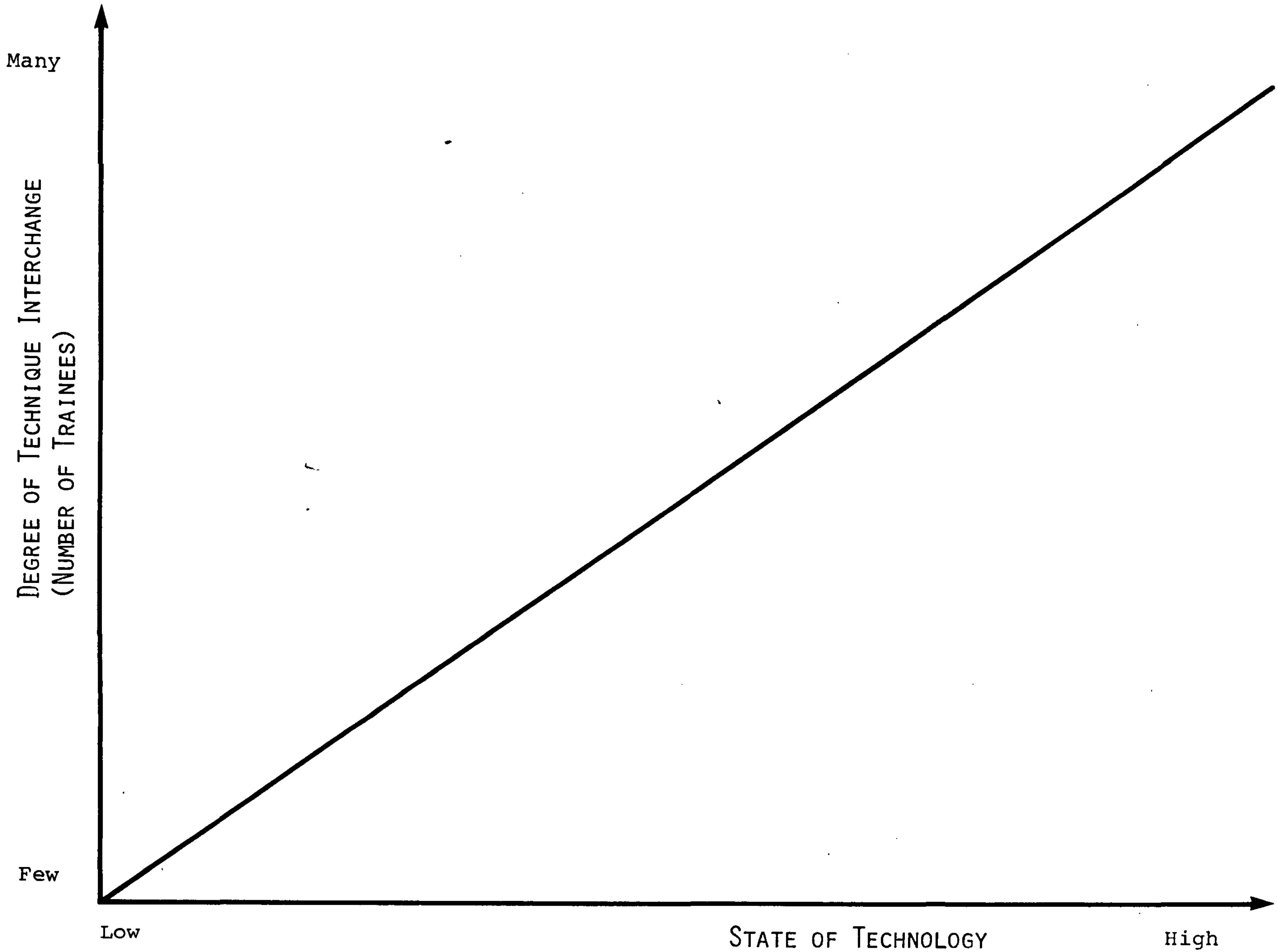
Understanding these parameters and their interrelationships for any particular technique interchange will facilitate planning, estimating the success and carrying out a technique interchange program.

The relationship between the degree of technique interchange achievable and the state of the technology for a given time constraint is basically linear as shown in Figure 1. In this Figure the number of trainees has been used as the primary measure of technique interchange. While it is recognized that all trainees may not use a new technique on a regular basis, the number of trainees is a good measure of the throughput capability of a technique interchange program.

For purposes of technique interchange the state of the technology may be measured in terms of the kind and amount of documentation that is available. As a technology develops, the kind of documentation available tends to span the range from the informal notes of the originator through technical reports, conference papers, dissertations and journal papers to tutorial materials such as lecture notes or text material. As each of these various types of documentation comes into being there is a corresponding increase in detail and clarity which in turn opens the technology to a wider audience.

A number of other factors can be superimposed on the basic linear relationship between number of trainees and degree of documentation. These are shown in Figure 2. Looking at line 1, the type of personnel that can be used to assist in the technique interchange process is listed in relation to the state of the technology and degree of technique interchange. When the state of the technology is low (i.e., recent developments, little documentation) the only type of individual who can successfully tell someone else about the technology is the technical expert who developed the technology. At most this person can instruct only a few other individuals. As a technique develops understudies of the originator (colleagues, graduate students) become familiar enough with the technique to be able to explain it to others, thus providing the potential for training a larger number of people. When technical counterparts at other organizations learn enough about a technique that they can begin to pass the information on to their colleagues the number of potential trainees is expanded even further. A technique important enough to warrant having a person spend a significant portion of his or her time explaining or instructing in the technique results in the development of persons to act as tutors. Finally as the technology becomes fully developed with accompanying tutorial documentation individual learners can be counted on to learn about the new technology on their own.

Line 2 on Figure 2 illustrates the type of documentation and visual materials that are generally available as a new technique developes. When the only available documentation are the original notes of the technical expert who originated the new technique only a limited amount of technical interchange can take place. Technical reports and their illustrations allow a larger number of people



Many
Few
DEGREE OF TECHNIQUE INTERCHANGE
(NUMBER OF TRAINEES)
Low
High
STATE OF TECHNOLOGY
(AMOUNT OF DOCUMENTATION)

Figure 1.

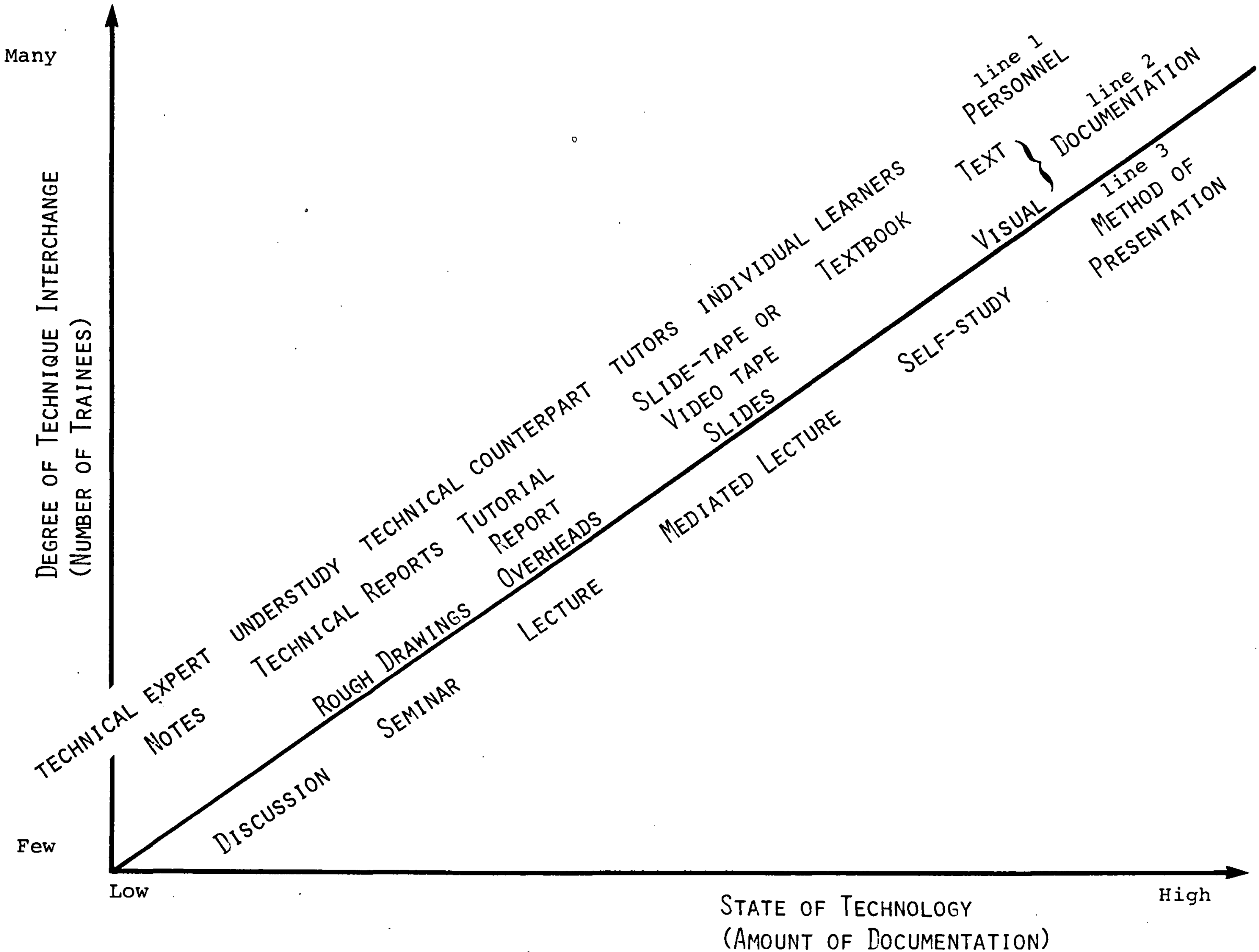

Many
Few
Degree of Technique Interchange
(Number of Trainees)
Low
High
State of Technology
(Amount of Documentation)
line 1
Personnel
line 2
Documentation
line 3
Method of
Presentation
Technical Expert
Understudy
Technical Counterpart
Tutors
Individual Learners
Text
Notes
Technical Reports
Tutorial
Report
Slide-tape or
Video tape
Textbook
Visual
Rough Drawings
Overheads
Slides
Discussion
Seminar
Lecture
Mediated Lecture
Self-study

Figure 2.

to have access to the new idea or method. Tutorial reports that can be used by technical counterparts at other organizations permit access to a wider audience. Such documentation is usually complete enough to transfer the technique to personnel at other organizations. Development of slide-tape or videotape presentations makes it possible to schedule regular classes or permit individual learners to have access to the technology on a demand basis. A text book in a technical area essentially makes the technology available to the world.

Line 3 of Figure 2 shows different types of instructional methods in relation to the type of personnel used to transfer the technology and the type of documentation/illustrations available. The originator of a technique can work from his notes and by means of a discussion with one or two other technically qualified people transfer the technique to them. Larger groups can be handled in a seminar setting. This format works best if there is at least a technical report available around which the discussion can be centered. The lecture format can be used for still larger groups but because there is less opportunity for discussions, written material in the form of tutorial reports should be available. When tutors are available mediated lectures can be used. This facilitates making the lectures available on a repeating basis and increases schedule flexibility. With sufficient tutorial documentation individual learners can acquire knowledge about a new technique through self-study.

Figure 1 illustrates the relationship between the state of development of a new technique and the number of persons to receive the technique. Figure 2 shows personnel, documentation and teaching method parameters superimposed on this basically linear relationship allowing one to visualize these interrelationships. It is important to restate that these Figures show the relationship between the state of the technology and degree of technique interchange for a fixed time constraint. Many people could learn about a new technique directly from the originator through a series of seminars which is repeated over and over again. However, unless this person's role in the organization is going to change, this usually would not be an appropriate course of action. Rather, if a large number of people is required to have access to the technology, an investment should be made in personnel and materials to accomplish the job.

Time is another fundamental parameter influencing technique interchange. Time constraints can be of several forms:

How soon do people need to be trained?

Will they be trained in a group or individually?

Will training availability be required over an extended time?

All of these quesitons must be addressed when planning a technique interchange.

Planning a Technique Interchange

The steps in planning a technique interchange may be summarized as follows:

- Determine the number of people desiring access to the technique
- Determine temporal constraints
- Assess present state of documentation
- Decide on most appropriate instructional format
- Prepare additional documentation as needed
- Offer training
- Evaluate success of technique interchange

When planning a technique interchange the fundamental parameters discussed in the previous section should be kept in mind. Determining the number of people requiring access to the technology provides information for making a decision as to what is the most desirable kind of documentation to have. If only a few (3 to 4) people are involved, it does not make sense to write a text book. If 60 people need to be trained some sort of tutorial documentation is necessary.

Temporal constraints have a large impact on planning a technique interchange. If immediate training is needed there will not be time to produce any significant amount of documentation beyond that which is already available. This may necessitate following a procedure which is known to be suboptimum. As an example, a situation may require 40 persons to be trained in the use of a new analysis algorithm on very short notice. If the only documentation available consists of a technical report describing the theoretical basis of the algorithm and a brief description of the kind and format of input data and variables required, one would not expect to get well-trained, competent users of the new algorithm by exposing them to a few hours of lecture. However, if this is the only choice available, it will be the one used. Therefore, one should be aware that the training program is suboptimum and judge the results accordingly.

If training is required to be available over an extended time, it is desirable to prepare special instructional materials. This can best be accomplished by using the experience of one presentation to improve upon the materials for the next presentation. Thus, over a period of time a good set of tutorial materials will evolve.

Having determined the number of people requiring access to the technique and the temporal constraints, one should make an assessment of the present state of documentation. This assessment will reveal whether or not a successful technique interchange can take place. By examining the present state of documentation in relation to the number of people requiring access to the technique, a decision can be made as to whether or not additional documentation is required and whether it is possible within the time available.

Based upon the information obtained so far, a decision can be made on the most appropriate instructional format. If little documentation is available and time constraints require that instruction take place immediately, a one-on-one tutorial format or small group seminar would be most appropriate. If the seminar format cannot accomodate the number of people required to receive instruction on the new technique, it may be necessary to repeat the seminar a number of times. While lack of documentation may suggest the use of a seminar format, a large number of students would require that this seminar be repeated many times. This in itself is time consuming. In that situation it may be more advantageous to prepare additional documentation for use in a lecture format.

Having assessed the present state of documentation, decided on the most appropriate instructional format, and prepared additional documentation as required, the training program may be offered.

The final step in planning a technique interchange is to devise a method for evaluating the success of the technique interchange. One of the best ways to achieve this is to set down operational or behavioral objectives for the training program and a series of tests or exercises to determine whether or not trainees have met these objectives. Questionnaires may also be used to evaluate the technique interchange program.

Guidelines for Carrying Out a Technique Interchange

To carry out a technique interchange it is important to identify key individuals in each organization to oversee the planning, preparation, technical interchange, and evaluation steps of the process. Regular communication between these two individuals will help to insure that the expectations of personnel within both organizations are realistic.

One of the planning steps described above was to decide on the most appropriate instructional format. This decision cannot be made independent of time and documentation constraints so that one cannot specify absolute guidelines for choosing the proper instructional format. In the absence of any time constraint and assuming necessary documentation is available, Figure 3 provides useful information for choosing an appropriate instructional format. One-on-one tutoring works quite successfully if the number of participants is rather small, one to six people. A seminar consisting of discussion and/or workshops works well for medium size groups, say four to fourteen people. Lectures coupled with individual exercises can be used quite successfully with groups as large as 35. Special techniques, usually involving skillfully prepared self-study materials, are required when a very large number of individuals

GUIDELINES FOR CHOOSING APPROPRIATE INSTRUCTIONAL FORMAT

NUMBER OF PARTICIPANTS	FORMAT
1 - 6	ONE-ON-ONE TUTORING
4 - 14	DISCUSSION/WORKSHOPS
10 - 35	LECTURES/INDIVIDUAL EXERCISES
30 - 300	SELF-STUDY MATERIALS

Figure 3.

is to participate in the program.

A number of schedule factors must be accounted for when carrying out a technique interchange. These factors include:

- The date on which training activities are to begin
- Amount of time needed for training
- Time span over which training will take place
- Replication of training programs as required.

In establishing a date on which training is to begin, allowance must be made for materials preparation. Guidelines for the preparation of various types of materials are discussed below. Consideration should also be given to human factors when planning a training schedule. For instance, if it is estimated that a particular program will require 16 hours of lecture instruction, the program is likely to be more successful if this is spread out over a 4-day period rather than requiring participants to sit in 8 hours of lecture two days in a row. This is especially important in situations when participants in the program have other duties. By using a mixture of instructional formats, such as alternating lectures with workshop periods, it is possible to carry out more effective "full-time" training programs than if a single instructional format were used. If scheduling permits, the time span over which the training program will take place should be two to three times longer than the amount of formal instructional time. This will allow time for participants to attend to other duties or to review difficult concepts.

The amount of time required for the preparation of different types of instructional materials is shown in Figure 4. These time estimates are based on the assumption that the person preparing the materials is devoting 1/4 to 1/3 time effort on the materials preparation project. The lead times indicated also allow for the review of materials by technical colleagues and, in the case of mediated materials, time for art work, photographic services, etc., has been included in the estimate.

Whenever possible, the preparation of instructional materials should be carried out in 4 steps:

- Draft materials
- Technical review
- Student tryout
- Rewrite

The materials may be drafted by the originator of the technology or an associate who is familiar with the area. Technical review should be carried out by the originator of the technique or a person

GUIDELINES FOR DETERMINING TYPE OF DOCUMENTATION

NUMBER OF PARTICIPANTS	TYPE OF DOCUMENTATION	LEAD TIME REQUIRED
1 - 6	TECHNICAL EXPERT'S NOTES	6 - 9 DAYS
4 - 14	TECHNICAL REPORT	6 - 9 WEEKS
10 - 35	TUTORIAL PAPERS	3 - 4 MONTHS
	STUDENT EXERCISES	
30 - 300	SELF-STUDY MATERIALS	
	ROUGH VIDEO TAPES	4 - 6 MONTHS
	ROUGH SLIDE/TAPE/STUDY GUIDES	
	TUTORIAL NOTES	6 - 9 MONTHS
	CASE STUDIES	
300 - 3000	TEXT BOOK	1 - 3 YEARS
	PROFESSIONALLY PRODUCED A.V. MATERIALS	

Figure 4.

who is thoroughly familiar with the technical aspects of the material to be presented. The material should then be reviewed by a typical "student", often a junior staff member working in a related area. Based upon the technical review and student tryout, materials are rewritten prior to use with the training group.

Once the instructional format has been decided, scheduling taken care of, and necessary materials prepared, the technique interchange process can begin. Personnel serving as instructors should be sensitive to participants' reaction and their ability to absorb the material as presented. "On line" modifications should be made as required. A post-training follow-up and evaluation provides valuable input for replication of the training program or the planning of other technique interchanges.

Summary and Recommendations

This part of the technique interchange plan has identified and discussed fundamental parameters which should be taken into account when planning procedures for the interchange of techniques between two technical organizations. Steps for planning a technique interchange were summarized and discussed and guidelines for carrying out a particular program were presented.

It is recommended that this document be used as a planning aid for two trial technique interchange programs. One program should involve transfer of techniques and capabilities from Purdue/LARS to NASA/JSC. The other program should involve transfer of techniques from NASA/JSC to Purdue/LARS. Candidate subject matter material for the former technique interchange include the computation capabilities available to JSC via the remote terminal and the LARS computer facility. Candidate subject matter for the latter technique interchange is the P1 analysis procedure and its support computer programs.

Reference

Phillips, T.L., H.L. Grams, J.C. Lindenlaub, S.K. Schwingendorf, P.H. Swain and W.R. Simmons. Remote Terminal System Evaluation. LARS Information Note 062775.

B. Scanner System Parameter Selection

I. Introduction

The Scanner System Parameter Selection project consisted of three tasks plus planning and reporting during the contract period. These tasks are part of a program developing analytical and simulation models for remote sensing systems. The models are intended to permit evaluations of parameter sets and to enable optimization of scanner system design for a given remote sensing task. Progress on those tasks is detailed in the following sections. The task numbers refer to those defined in the implementation plan submitted for this contract.

II. Task 2. Test and Evaluate Classification Error Prediction Algorithm.

In the previous contract a classification error estimating algorithm was developed and applied to multispectral data, specifically the data developed for the thematic mapper simulation study [1]. Appropriate comparisons were reported with favorable results. In this contract a more complete and convincing evaluation of the error estimating algorithm was conducted. Multispectral Landsat data was classified and the resulting classification accuracy was compared with the output of the error predictor. Three test areas were selected: (1) Ogle County, Illinois, (2) Graham County, Kansas, and (3) Grant County, Kansas.

a. Ogle County, Illinois.

This data is a portion of Landsat scene 1017-16093 acquired August 9, 1972, and has a LARS runtable entry of 72032806. Three training classes were used and classification was performed using four spectral bands, i.e. channels 1 thru 4. Table 2b-1. shows both the classification accuracies obtained using the LARS point classifier and the error prediction algorithm estimates.

Table B-1. Classification Performance Comparison for Ogle County, Illinois, August 9, 1972.

Class	No. Points	Pt. Clsf.	Error Prediction Algorithm
Corn	411	87.3	91.7
Soybean	224	90.6	91.3
Other	217	94.0	90.6
Overall	852	90.7	91.2

b. Graham County Kansas.

This data set is LACIE SRS segment 1018 and has a LARS runtable entry of 74028500. Channels 9 thru 12 or the acquisition corresponding to Landsat scene 1672-1644, were used. Four training classes were developed from 229 training fields. Results are tabulated in Table B-2.

Table B-2. Classification Comparison for Graham County, Kansas, May 26, 1974.

Class	No. Points	Pt. Clsf.	Error Prediction Algorithm
Baresoil	443	65.9	78.3
Corn/Sorghum	99	89.9	91.0
Pasture	1376	98.4	95.1
Wheat	459	94.8	93.9
Overall	2377	87.2	89.6

c. Grant County, Kansas.

This data set is LACIE SRS segment 1036 and has a runtable entry of 74027600. Channels 5 thru 8 or the acquisition corresponding to Landsat scene 1655-16512, were used in the classification study. Five training classes were developed from 388 training fields. Results are tabulated in Table B-3.

Table B-3. Classification Comparison for Grant County, Kansas, May 9, 1974.

Class	No. Points	Pt. Clsf.	Error Prediction Algorithm
AG 1	793	52.3	59.3
AG 2	446	75.8	73.3
AG 3	134	90.3	88.8
Nonfarm	762	94.9	90.5
Wheat	930	82.7	79.7
Overall	3065	79.2	78.3

d. Simulation of Graham County Statistics.

A further test was conducted on the following basis: Normality of the statistics of the multispectral data is generally accepted feature. Whenever a new method is developed, however, its performance cannot be evaluated satisfactorily because any deviations from the desired results could be attributed to the non-normality of the particular data set. If this element of uncertainty could be eliminated from the analysis, then any inadequacies can be traced back to the algorithm rather than to the non-normality of the data.

This goal is achieved by generating synthetic normal data which has the same statistics as the multispectral data but is statistically Gaussian. The algorithm that accomplishes this task uses the statistics of an already classified area and generates random numbers having appropriate class statistics. There is a one-to-one correspondence between the field coordinates in the simulated data and the original data. This simulated data is classified by LARS point classifier and its classification accuracy compared with the error predictor algorithm estimates. Results are shown in Table B-4.

Table B-4. Comparison of Classification Performance Using Simulated Data.

Classes	Pt. Clsf.	Error Prediction Algorithm
Class 1	50.1	69.0
Class 2	86.9	86.0
Class 3	92.9	90.6
Class 4	89.1	84.9
Overall	79.7	82.6

These results are not as conclusive as expected. The LARSYS and error estimation model results were judged not to be close enough throughout the various classes. In examining the histograms of the aritificial data, it was noted that the statistics are not as close to a normal distribution as we expected. The following discussion explains this result. The simulation algorithm generates the data while conserving a geometrical correspondence with the real data. It is true that the total number of points in the entire class is normally distributed; however, only the training fields are used in classification and error probability calculation. Training fields, being a subset of the entire class, did not exhibit normality to the degree desired. Moreover, their statistics, if recomputed, showed deviations from the desired statistics. Therefore, a different simulation process was examined. This algorithm does not preserve any spatial correspondence between the real and artificial data.

It generates a specified number of pixels according to the given distribution. The two histograms are shown in Figure B2-1. The newly generated artificial data was classified by the maximum likelihood point classifier.

Error predictor estimates being a function of the class statistics alone, were unchanged from the previous case. The comparison is given in Table B-5.

Table B-5. Comparison of Classification Performance of Point Classification of Simulated Data and the Predicted Error.

Class	Point Classification Simulated Data	Error Prediction Algorithm	Accuracy Difference
Bare Soil	77.8	78.3	0.5
Corn	91.2	91.0	0.2
Pasture	95.3	95.1	0.2
Wheat	94.2	93.9	0.3
Overall	89.6	89.6	

The classification accuracies obtained by these two independent methods is extremely close. Slight variation in error rate will occur in the point classification of simulated data results if a different set of random data is used in classification. Table B-6 shows the probability of correct classification for three cases when a different starting point is specified for the random number generator.

Table B-6. Comparison of Point Classification of Simulated Data with Different Initial Conditions on Random Number Generator

Class	Random start #1	Random start #2	Random start #3
Bare Soil	77.0	79.7	79.0
Corn	91.2	92.1	91.0
Pasture	94.8	96.1	95.0
Wheat	94.0	94.2	94.8
Overall	89.2	90.5	90.0

```
56 I
52 I
48 I
44 I                 3
40 I                3*1
36 I              33*** 1*
32 I              ***** **  1
28 I              *****2*****21
24 I              *************
20 I              *************
16 I              2************
12 I              *************
 8 I             2*************3*
 4 I         11 1*****************2*3
   I----+----+----+----+----+----+----+----+----+
0.5000               40.50               80.50
```

Histogram for channel 3 Simulation, version 1

```
238 I                    9AAD
221 I                    ****
204 I                   7****B
187 I                  1******
170 I                  *******
153 I                  ******E
136 I                 D*******7
119 I                4*********
102 I                **********9
 85 I               5***********6
 68 I              3*************A
 51 I              ***************4
 34 I             B****************
 17 I      1 213A******************FC661     1
    I----+----+----+----+----+----+----+----+----+
 0.5000              40.50               80.50
```

Histogram for channel 3 Simulation version 2

Figure B-1. Comparison of Simulated Data Histograms Before and After Software Modification.

The overall classification accuracies obtained by LARSYS varies slightly above and below the error prediction algorithm result. This example illustrates two points. One is that the error model estimates are close to the classification results from simulated normal data. The second and more interesting point is that by using this estimator we were able to predict the non-normality of the original data or, more likely, the selection of a set of training fields not completely representative of the entire class. Although it is widely assumed that multispectral data has a normal distribution, in practice this assumption is not completely satisfied. Using the results just reported we can investigate the effect of non-normality of the data in the classification accuracy.

Comparison of the entries in Table B2-2 and Table B2-5 show that the classification of the original Landsat data is about two percent less accurate than the classification of the simulated normally distributed data. This could be the result of either the violation of the normal assumption in the original data or the lack of representativeness in the training fields.

d. Conclusion.

It was intended through these test runs to further validate the classification error prediction algorithm for obtaining correct classification accuracies. In the previous reports, correct classification accuracies were in the high 90% range and comparable results were obtained for both methods. The regions analyzed in this report, exhibit classification accuracies in the high 70, 80 and low 90% range. In all of the test runs, overall classification accuracies obtained through the error prediction method compared to the LARS point classifier was well within the analyst's tolerance; therefore making this method a viable alternative to the present classification scheme and a necessary tool in theoretical analysis of a multispectral scanner system.

III. Task 4. Karhunen-Loeve and Information Theory Scanner Model Development.

The goal of this research task is to develop an analytical procedure that will establish a theoretically optimal remote sensing system design. For a given scene, S, the class, ζ, of all possible spectral response functions in the scene is represented by a finite set of the possible waveforms. The goal is to arrive at an optimum representation of the scene by selecting sample response functions from the scene to represent the information classes within the scene. In addition, each waveform is represented in a form convenient for analysis. If the scene has been represented accurately, the information necessary to design and evaluate a classifier is available. The particular emphasis in this task is to use this procedure to design and evaluate possible sets of wavebands for sensors. This approach will allow the selection of the optimal set of features for all possible remote sensing problems and provide a standard for comparison of suboptimal systems. It should be pointed out that the procedure is to be repeated over many scenes such that the final evaluation extends over all possible scenes that may be observed by the sensor.

Two forms of spectral modeling were pursued. One is based on the well known Karhunen-Loeve expansion. The K-L expansion of a random process has the property that a waveform from the process can be represented by a linear combination of orthonormal basis functions with minimum mean square error.

The second method uses information measures taken from formal information theory. The results for the K-L approach will be discussed first.

a. Karhunen-Loeve Approach.

The minimum mean square error criterion will be the optimality criterion by which the quality of the K-L representation will be measured. The kernel of the integral equations which must be solved to obtain the orthonormal basis functions is the covariance of the random process for the scene S. The covariance is unknown, a priori and must be estimated from a finite set of waveforms. It is at this point that the choice of waveforms to represent the scene becomes important in the analysis.

It has been shown that increasing the number of measurements on a waveform may actually decrease the performance of a pattern recognition system [2,3]. Therefore, it is expected that an increase in the number of representation terms may increase the mean square error. In our procedure we want to account for the finite sample size and its affect on the number of basis functions that will be selected.

At this time an initial test data set has been assembled using 150 samples from three classes taken over Williams County, North Dakota, in August, 1975. An equal number of waveforms were taken from each of the classes wheat, fallow, and pasture. A software system has been set up to estimate the covariance for the waveforms, compute and order the orthonormal basis functions, and transform the original waveforms to finite dimensional vectors.

Once the transformation to finite dimensional vectors has been made the problem becomes a classical multivariate analysis problem. We assume that the process is Gaussian. The methods of estimation and classification for the multivariate Gaussian problem are well known.

While the overall procedure has been outlined, there are several steps that need further investigation. First, a systematic procedure is needed to select the waveforms to represent the scene. A better understanding of the effect this selection process has on the analysis is needed. A second problem is the relationship between the mean square representation error and the number of sample functions available. And third, the relationship between the representation error and Bayes classification error has not been established. Since classification error is a common performance measure in the pattern recognition literature, an analysis of this relationship is important.

During this contract period the software system was applied to the initial data set. The first four basis functions are shown in Figures B-2 through B-5. Improvements to the software system such as the graphing capability and better numerical techniques have been implemented.

b. Information Theory Approach.

The information theory approach is based on modeling the spectral response of a scene as a portion of a realization of a stochastic process in wavelength. This model is then used to evaluate the average (mutual) information for different bands of observed spectral scenes. Previous reports contain outlines of particular approaches taken to various aspects of the problem.

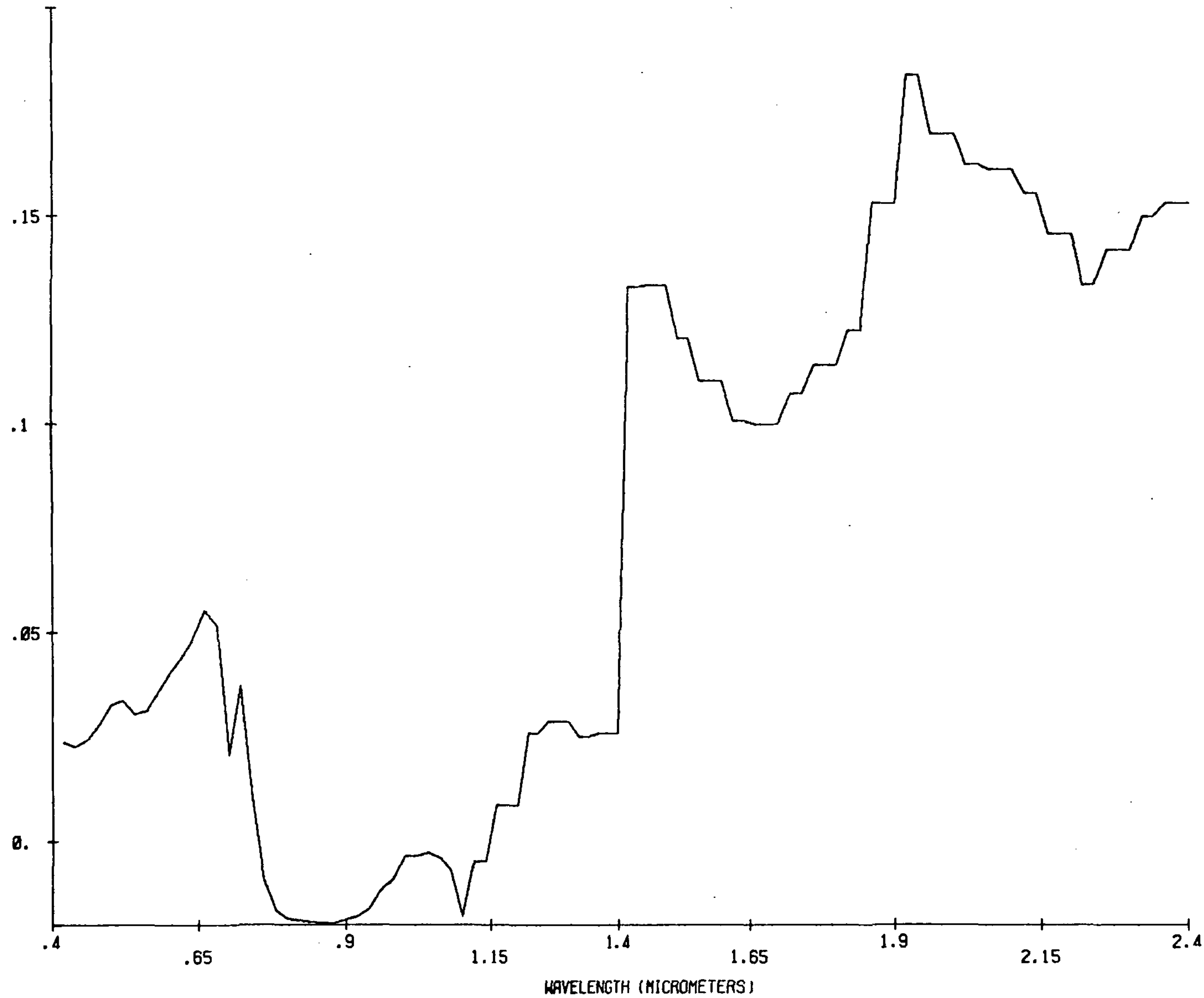


Figure B-2. Plot of First Eigenvector of Spectral Ensemble Containing Wheat, Fallow, and Pasture Classes.

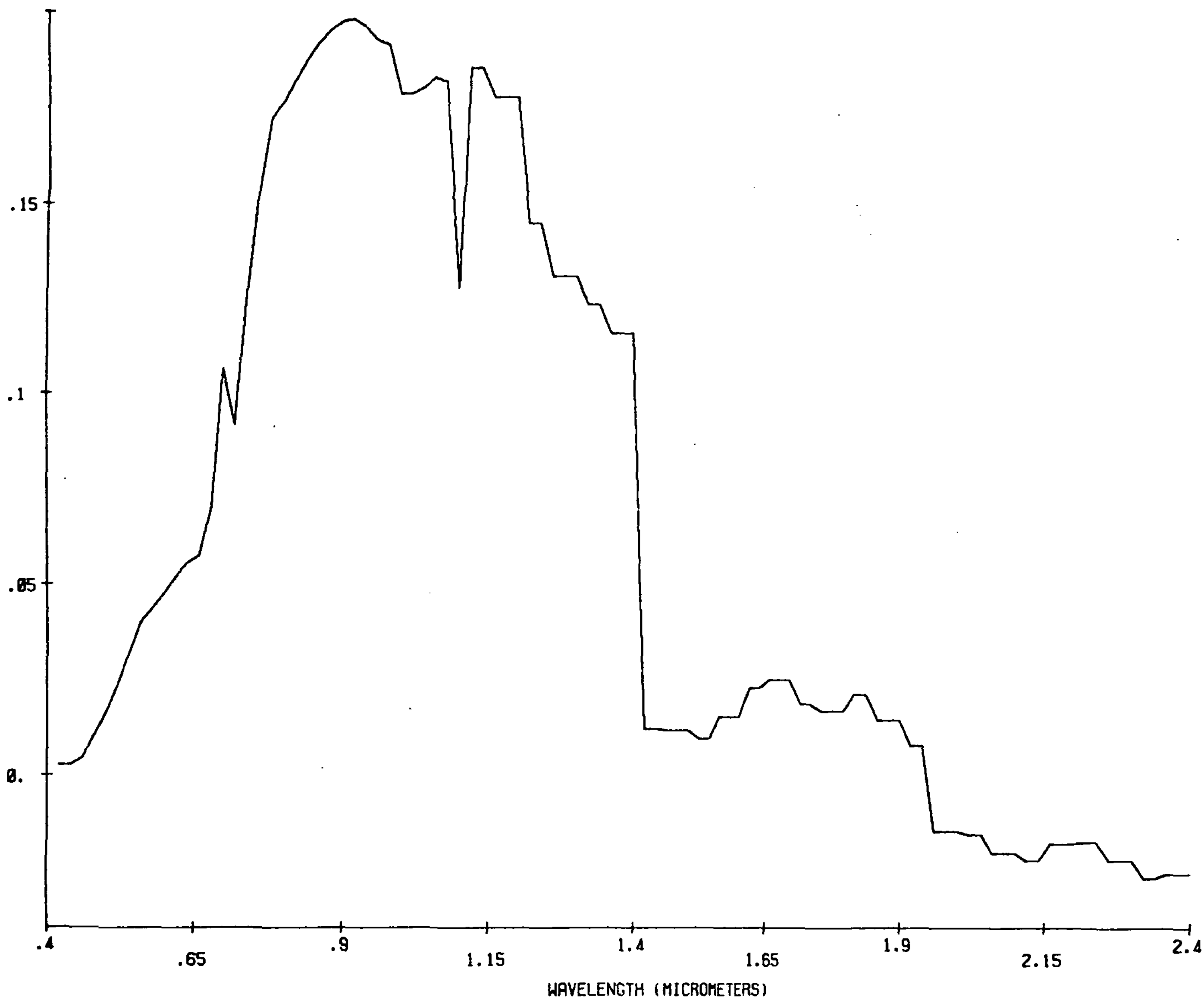


Figure B-3. Plot of Second Eigenvector of Spectral Ensemble Containing Wheat, Fallow, and Pasture Classes.

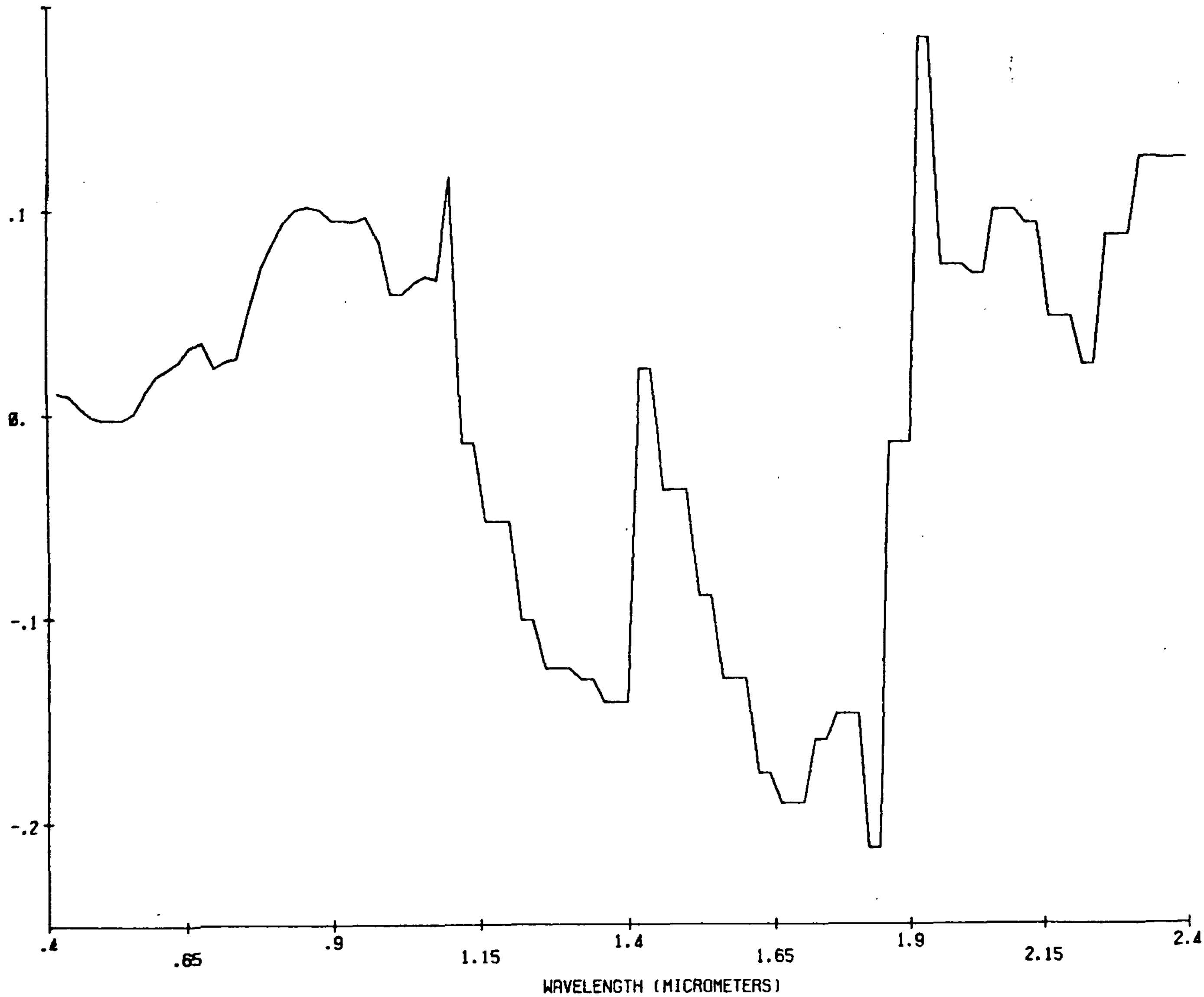


Figure B-4. Plot of Third Eigenvector of Spectral Ensemble Containing Wheat, Fallow, and Pasture Classes.

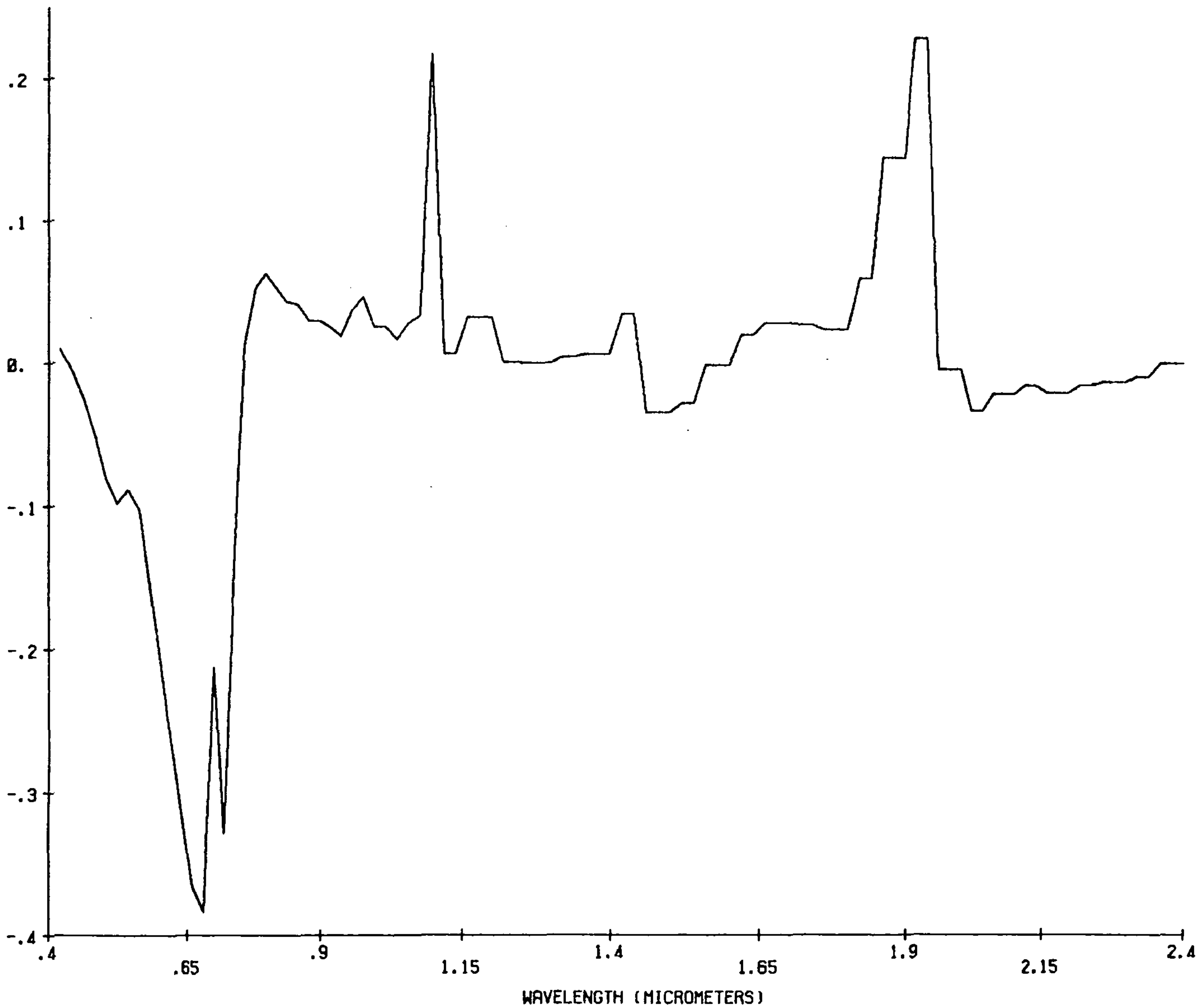


Figure B-5. Plot of Fourth Eigenvector of Spectral Ensemble Containing Wheat, Fallow, and Pasture Classes.

In particular, the relation of average information and Weiner filtering is outlined.

1. Modeling the Spectral Response of Different Scenes.

A major problem to be solved is finding adequate models for the spectral response of different scenes. To demonstrate the technique used in this research, models for two different types of spectral scenes are identified. One spectral scene is wheat, and the other spectral scene is an average spectral response for several agricultural crops combined. This combined spectral scene consists of: (1) oats, (2) barley, (3) grass, (4) alfalfa, and (5) fallow fields. These spectral scenes were arbitrarily divided into the spectral bands shown in Table B-7.

Table B-7. Wavelength Limits for the Spectral Bands.

	Wheat	Combined Scene
Band 1	.4528 - .5380μm	.4565 - .5402μm
Band 2	.5380 - .6239μm	.5402 - .6246μm
Band 3	.6239 - .7097μm	.6246 - .7097μm
Band 4	.7097 - .8517μm	.7097 - .8481μm
Band 5	.8517 - .9910μm	.8481 - .9850μm
Band 6	.9910 - 1.130μm	.9850 - 1.122μm
Band 7	1.130 - 1.344μm	1.122 - 1.307μm
Band 8	1.446 - 1.821μm	1.451 - 1.818μm
Band 9	1.959 - 2.386μm	1.967 - 2.386μm

For each band, three different model types of several degrees of complexity are hypothesized. An exception is Band 1 of the combined scene; this exception will be discussed later. The first model is the autoregressive (AR) model of order n defined by

$$y(k) = a_1 y(k-1) + a_2 y(k-2) + \dots + a_n y(k-n) + \omega(k) \qquad (1)$$

where

$y(k)$ is the value of the spectral response at the discrete wavelength k;

a_j, j=1, ..., n are coefficients to be identified; and

$\omega(k)$ are independent, identically distributed samples of a zero mean gaussian random process of variance σ.

The second type of model is the autoregressive plus constant (AR+C) model of order n defined by:

$$y(k) = c + a_1 y(k-1) + \dots + a_n y(k-n) + \omega(k) \quad (2)$$

where

C is a constant to be identified; and the other parameters are the same as in the first model.

The third model is the integrated autoregressive (LAR) model of order n. This model may be written as

$$\nabla y(k) = a_1 \nabla y(k-1) + \dots + a_n \nabla y(k-n) + \omega(k) \quad (3)$$

where

$$\nabla y(k) = y(k) - y(k-1);$$

Other parameters are as previously defined.

Another model is used for Band 1 of the combined scene. This model is used because the above three models could not be validated for Band 1 of the combined scene. The model used is an extension of the integrated autoregressive model, and is denoted as an integrated autoregressive of the second kind (IAR2) of order n. It is defined by

$$\nabla_2 y(k) = a_1 \nabla_2 y(k-1) + \dots + \nabla_2 y(k-n) + \omega(k) \quad (4)$$

where

$$\nabla_2 y(k) = y(k) - y(k-2);$$

Other parameters are as previously defined.

An excellent discussion of these models is given by Kashyap and Rao [4, Chap. 3].

The identification procedure for these models consists of estimating the coefficients a_j, j=1,...,n such that the model gives the best fit to the actual measurement data of the spectral bands. In this study, maximum likelihood identification techniques are utilized. Reference [4, Chap. 6] gives details.

For the wheat scene, each of the first three models are identified for orders n=1,...,10 for each of the spectral bands. The combined scene produced data that is not as smooth as that for the wheat scene. Therefore, the first three models are identified for orders n=1, ..., 15 for each of the spectral bands. The fourth model is identified for orders n=1, ..., 15 for Band 1. Hence approximately 700 possible models are identified. Of these models, one was selected to represent each band.

2. Selection of a Model for Each Spectral Band.

Selection of a model for a particular band is based on a criterion that included goodness of fit and reflected the principle of parsimony. Parsimony means that the model with the smallest number of parameters that adequately represents the spectral process should be used. The principle of parsimony is discussed in references [4, Chap. 8] and [5]. Each selected model is then subjected to various validation tests on assumptions about the model and similarity between statistical characteristics of the actual measurement data and simulated data generated from the model. These tests are discussed by Kashyop and Rao [4, Chap. 8]. It was during these validation tests that it was discovered that the model given by equation (4) was necessary to represent Band 1 of the combined scene. Only after passing all validation tests is a model accepted as representative of the spectral response process of a particular spectral band.

Based on the above techniques, the models identified as representing the spectral response processes of the respective spectral bands are shown in Table B-8.

Table B-8. Models for the Spectral Bands.

Band	Wheat models	Combined scene models
1	AR(6)	IAR2(11)
2	AR(2)	AR(2)
3	IAR(10)	IAR(11)
4	AR(1)+C	AR(1)+C
5	AR(1)	AR(3)
6	AR(2)+C	AR(1)
7	IAR(9)	AR(9)+C
8	IAR(9)	IAR(8)
9	IAR(6)	AR(1)

In the above table

AR(n) = autoregressive model of order n.
AR(n)+C = autoregressive plus constant model of order n.
IAR(n) = integrated autoregressive model of order n.
IAR2(n) = integrated autoregressive model of the second kind of order n.

These models are interesting in their own right. They give dynamic models for the spectral response in each band for the two different scenes. As mentioned in previous reports, these models are used to study the informational characteristics of the spectral bands. The models for the spectral bands are formulated in the above manner to take advantage of their useful computational properties. Let the observed spectral scene z(k) be written as

$$z(k) = y(k) + \nu(k) \tag{5}$$

where k is a discrete wavelength in the spectral interval (or spectral band) $[\lambda_1,\lambda_2]$ of interest. The term $\nu(k)$ represents the observation noise that is present at the multispectral scanner. Kalman filtering techniques may then be used with the models identified for the spectral bands to compute the average (mutual) information in the received spectral process z(k) about the spectral response y(k). These computations will aid in determining which bands in a spectral scene contribute the most average information.

3. Calculation of Average Information

The required Kalman filter expressions have been implemented on the LARS computer system for this study. Using this implementation average information for each of the different spectral bands for both types of scenes is computed. For demonstration purposes, the same value for the variance of $\nu(k)$ is used in all spectral bands for both scenes. This may not be entirely realistic since different noise disturbances may be expected in different spectral bands. However, it is thought that for first comparisons a constant variance for $\nu(k)$ is useful. Thus the results for the above computations are shown in Table B-9.

Table B-9. Average Information for the Spectral Bands.

Band	Average Information Wheat Scene	Average Information Combined Scene
1	17.6 nats	30.3 nats
2	4.9 nats	9.0 nats
3	11.7 nats	17.0 nats
4	17.7 nats	26.2 nats
5	36.6 nats	32.1 nats
6	24.0 nats	28.5 nats
7	43.3 nats	72.7 nats
8	35.2 nats	54.6 nats
9	34.1 nats	63.8 nats

(Note: "nats" is the unit of measure resulting from the use of natural logarithms. The unit of measure may be changed to "bits" by converting to logarithms of the base 2).

In the above table not all the spectral bands have the same spectral bandwidth. Thus, it is of interest to compare these results with those given in Table B-10 for the case of equal spectral bandwidths.

Table B-10 Average Information for Equal Spectral Bandwidths.

Band	Average Information Wheat Scene	Average Information Combined Scene
1	17.6 nats	30.3 nats
2	4.9 nats	9.0 nats
3	11.7 nats	17.0 nats
4	16.1 nats	24.3 nats
5	36.6 nats	32.1 nats
6	24.0 nats	28.5 nats
7	32.1 nats	51.9 nats
8	28.5 nats	45.0 nats
9	24.2 nats	45.9 nats

It is thought that the average information in the combined scene is higher in absolute terms than the wheat scene because the variation in the spectral response of the combined scene is higher. That is, the spectral response in wheat scene is "smoother" than in the combined scene. The relative value of the average information between different spectral bands within each scene type is the more important parameter. These relative values determine which subset of spectral bands provide the maximum average information for observing a particular scene type. The variations of average information among spectral bands are important topics for further study.

4. Further Investigations

These information theoretic ideas will be pursued further. A particular avenue of approach is to calculate average information in the different spectral bands for different noise levels $\nu(k)$. Models for spectral scenes other than wheat and the combined scene merit study. Relation of average information and the classification of observed spectral scenes needs further research. These studies should eventually lead to better analytical understanding of some multispectral scanner parameters.

In order to more fully explain the information theory approach being pursued for scanner modeling a brief tutorial discussion has been prepared. This material is presented as an appendix to Section B2. Scanner System Parameter Selection.

IV. Tasks 3 and 6. Spatial Modeling and Noise Modeling.

The effort in spatial modeling task has been denoted to specific software development. In particular a convolution algorithm has been implemented which effectively can simulate any scanner point spread function and the resultant output. Also, software is now available to simulate or add random noise, according to any specified signal-to-noise ratio, to the multispectral data. These two programs should complete the software package required in the Scanner System Parameter Selection task.

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Appendix B-1. Information Theory Techniques for Analyzing Parameters of Multispectral Scanner Systems.

I. Introduction

In many remote sensing problems a multispectral scanning device is the major data collection system. The collected data is then processed in a manner that reflects the purpose for which it is to be used. An example of a typical use for a multispectral scanner is the Landsat earth resources satellite. The data gathered by the satellite is used to provide information about agricultural scenes, natural resources, land utilization and others. A particular use for the data is the classification of crops in agricultural areas.

There are many parameters to be considered when a multispectral scanner system is selected to study a particular problem. The main area of interest for this study lies in the use of the multispectral scanner for agricultural purposes. Some of the parameters of interest are placement of spectral bands within the spectrum, spectral bandwidth, and signal-to-noise properties. Other parameters are spatial resolution, spatial sampling methods, and utilization of ancillary data. Another parameter of interest is the specific types of scenes to be observed.

At the present time, the studies concerning selection of multispectral scanner parameters have been mostly ad hoc and empirical. Landgrebe, Biehl and Simmons [1] have completed an extensive empirical study of multispectral scanner system parameters. In this study, several parameters were chosen and the resulting hypothesized multispectral scanner was simulated to judge its performance. The performance criteria used were classification accuracy and the root-mean-square (r.m.s.) error in proportion estimation.

It would seem advantageous to develop analytical techniques to study and select multispectral scanner parameters. Very little work has been done in this respect until the present efforts at LARS. Currently there are two subtasks in the Scanner System Parameter Selection task concerning scanner modelling and another subtask on approximate evaluation of classification error for the multiclass classification problem. One of the scanner modelling subtasks approaches the problem from an information theoretic viewpoint. Discussion of this informational viewpoint is the subject of the remainder of this paper.

II. Informational Viewpoint

Consider a scene as a source producing information in the form of its spectral reflectance response. If it is assumed that this response is a random process in wavelength, then information theoretic techniques may yield some useful results for determination of desirable multispectral scanner parameters. The multispectral scanner may be considered as a receiver observing a noise corrupted version of the spectral response process. That is, assume a model for the observed spectral process of the form:

$$z(\lambda) = y(\lambda) + n(\lambda) \qquad \lambda_1 \le \lambda \le \lambda_2$$

where

$z(\lambda)$ is the observed spectral process;

$y(\lambda)$ is the spectral reflectance process of the scene;

$n(\lambda)$ is noise disturbance process;

and

$\lambda \varepsilon [\lambda_1, \lambda_2]$ is the spectral observation interval.

Now, the noise process will cause some loss of information about the spectral scene. It is desireable to minimize this information loss. Stated in another manner, it is desired to maximize the information in $z(\lambda)$ about $y(\lambda)$. This may also be interpreted in an information theoretic sense. Suppose the spectral response $y(\lambda)$ is one of several possible classes $C_1, \ldots, C_M$. Then the above result may be stated in terms of average mutual information in $z(\lambda)$ about $y(\lambda)$ for class C_j:

$$I(y;z|C_j) = \int_Y \int_Z p(y,z\,C_j) \log \left\{ \frac{p(y|z,C_j)}{p(y|C_j)} \right\} dydt = E \left\{ \log \left[\frac{p(y|z,C_j)}{p(y|C_j)} \right] \right\}$$

$$= H(y|C_j) - H(y|z,C_j) \quad , \qquad \text{in the interval } [\lambda_1, \lambda_2],$$

where $H(y|C_j)$ and $H(y|z,C_j)$ are entropies. Thus it is desired to maximize the above expression. If each class C_j occurs with probability $P(C_j)$, $j=1,\ldots,m$; and

$$\sum_{j=1}^{m} P(C_j) = 1;$$

then averaging $I(y;\, z|C_j)$ over all the classes gives:

$$I(y;\, z|\underline{C}) = \sum_{j=1}^{m} P(C_j)\, I(y;\, z|C_j).$$

This may be interpreted as the average mutual information in $z(\lambda)$ about $y(\lambda)$ given the set of classes $\underline{C} = \{C_1, \ldots C_m\}$. Hence $I(y;\, z|\underline{C})$ may be a useful concept to study for the observation of several classes of spectral scenes.

Practical multispectral scanners are usually designed in terms of spectral bands. Thus one avenue of study would be to use the above criterion to provide an analytical method of choosing a set of spectral bands for a multispectral scanner. This approach will be carried out in the following manner. Divide the spectral response into several bands as shown below.

For many applications (i.e., classification) it is desired to use a subset of the total possible spectral bands. It is desirable to choose a subset of bands and still maximize the average mutual information about the scene given by the subset.

All of the above concepts of using mutual information presuppose a useful method for computation of the mutual information. It is thought that such a technique has been developed. In order to use analytic techniques for computation it is first necessary to develop adequate models for the spectral processes of interest. The modeling techniques used are based on concepts of model identification used in the area of time series analysis. A specific identification technique that seems most useful is the sequential Bayesian (and conditional maximum likelihood) technique. An excellent discussion of the technical details of the above method is given by Kashyap and Rao [2]. The basic idea of the method is to identify parameters for hypothesized models. The best model is then chosen according to an appropriate selection criterion. This model is then subjected to various validation tests. If the model passes the validation tests it may then be considered a valid model for the process. Failure of the validation tests implies that perhaps one should search for another model. Models currently being studied for spectral processes are forms of autoregressive models and integrated autoregressive models. These models are fairly simple and seem to give reasonably good characterization of the spectral processes. Furthermore, these models are of a form that is readily amenable to computation of mutual information in a received process $z(\lambda)$ about a spectral process $y(\lambda)$. An example of the form of a spectral model is as follows:

An autoregressive (AR) model for the spectral response is hypothesized of the form:

$$y(k) = a_1 y(k-1) + a_2 y(k-2) + w(k)$$

where

a_1, a_2	are coefficients to be identified
k	is an integer that corresponds to a discrete wavelength
$w(k)$	are independent, identically distributed samples of a Gaussian random process.

The procedure is then to identify the coefficients a_1 and a_2 from empirical data gathered about the scene. An example of such data would be detailed spectral response data for wheat. The model is then subjected to validation tests which concern assumptions made on w(k) and similarity of statistical characteristics of the model and the empirical data.

A model of the form given above may be placed in a form that is more amenable to computation techniques. This form, known as a linear state variable form, is the modern conventional form for dynamic models. An outline of the procedure for obtaining such a form is given in reference [3]. Application of this technique to the model of the previous example is shown below.

Define:

$$x_1(k) = y(k-1) = x_2(k-1)$$

$$x_2(k) = y(k) = a_1 y(k-1) + a_2 y(k-2) + w(k)$$

Or in matrix form:

$$\underline{x}(k) = \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ a_2 & a_1 \end{bmatrix} \begin{bmatrix} x_1(k-1) \\ x_2(k-1) \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} w(k)$$

Thus

$$y(k) = [0 \quad 1] \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix}$$

The observed spectral process may then be written as:

$$z(k) = y(k) + n(k)$$

where n(k) is a sample of the noise process.

As stated previously a model of this form will be useful in the calculation of mutual information. Since the observation (by the multispectral scanner) is corrupted by noise there is uncertainty about the state, $\underline{x}(k)$, of the process. It is clear that knowledge of the state of the process is equivalent to knowledge of y(k). Thus the quantity of interest is the mutual information between the state of the process and the estimate, $\hat{\underline{x}}(k)$, of the state of the process. Denote this mutual information as $I(\underline{x}, \hat{\underline{x}} | C_j)$. It may be shown that the procedure that maximizes this information also is the procedure which minimizes the quantity $E[\tilde{x}^T\tilde{x}]$ where $\tilde{x} = (x - \hat{x})$ [4]. It is well known that the Kalman filter procedure minimizes the covariance of the estimation error $E[\tilde{\underline{x}}^T\tilde{\underline{x}}]$ for a model of the linear state variable form [5]. Consider the application of this result to the previous model.

If $y(k) = x_2(k)$

and the estimate of $y(k)$ based on $z(k)$ is given by

$$\hat{y}(k) = \hat{x}_2(k)$$

Then the maximum mutual information in $z(k)$ about $y(k)$ is given by:

$$I(y,z|C_j) = I(x_2, \hat{x}_2|C_j)$$

Thus we have a technique for determining the maximum mutual information in $z(k)$ about $y(k)$ (for each k) within the limitations of the model. Also it should be noted that the Kalman filter technique gives the optimal (in a mean square sense) estimate of the actual spectral reflectance process. The limitation of this technique seems to be primarily due to the limitations of the accuracy of the model of the spectral process.

It has been shown by R. Y. Huang [6] that for a continuous Gaussian process the information in the observed process about the spectral response process between the wavelengths λ_1 and λ_2 is given by:

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

where $h(\lambda,\lambda)$ is the optimal Weiner filter for estimating $y(\lambda)$ from $z(\lambda)$. It can be shown that the optimal Kalman filter and the optimal Weiner filter give identical results [5]. The Kalman filter gain is written as a column vector of the same order as the state vector. However, due to the particular form of our state model, the only term of interest is the last element of the column vector. Also, since we are dealing with a discrete model, the integral in the preceding equation is replaced by a summation. Thus the above equation is replaced by a summation. Thus the above equation for mutual information may be written as

$$I(y;\ z|C_j) = \sum_{k\epsilon[\lambda_1,\lambda_2]} k_n(k)$$

where $K_n(k)$ is the n^{th} (n is the order of the state vector) element of the column vector Kalman gain expression.

Thus a technique has been developed to compute mutual information for any portion (or band) of the spectral response process. The implication is clear. To select a subset of bands, it is necessary to compute the mutual information for each possible band and then choose the subset that gives the largest overall mutual information. For choosing a set of bands to observe a number of classes the problem is more complicated. Recall that in this case we are dealing with the mutual information as given by:

$$I(y;\, z|\underline{C}) = \sum_{j=1}^{m} P(C_j)\, I(y;\, z|C_j)$$

Thus the problem of finding an overall set of bands may require the use of a search routine on a computer. At any rate, the technique is clear.

The relation of the above technique to performance of a multispectral scanner in terms of classification accuracy is complicated. It appears, at the present time, that performance may have to be specified analytically only in terms of bounds on classification accuracy. This is a problem that remains to be pursued.

III. Summary

An overview of an analytic technique for studying some multispectral scanner parameters has been given. In particular, an informational technique has been considered for selecting spectral bands for multispectral scanners. The relationship of the analytic parameters to classification accuracy remains to be considered in more detail.

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