SECTION 28

A SUMMARY OF MICHIGAN PROGRAM FOR EARTH RESOURCES INFORMATION SYSTEMS

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by

Jon D. Erickson
Willow Run Laboratories
The University of Michigan
Ann Arbor, Michigan

INTRODUCTION

This paper is a summary of and guide to the NASA-sponsored program carried out in 1971 at The University of Michigan's Willow Run Laboratories in earth resources information systems which employ multispectral remote sensing. The objectives of this program are to improve automatic techniques for extracting information from multispectral scanner data about the amount, location, and condition of remotely sensed objects of user interest and to reduce the costs of achieving such information on an operational (or research) basis from aircraft and satellites such as ERTS or SKYLAB - in short, to achieve a practical tool for planners and decision makers.

The program has four major areas of activity as shown in the table below:

1. Improved Throughput Parallel Processing Systems
2. Improved Processing Techniques
3. Show Practical Use in User Applications
4. Improved Sensors

The first area is a program to achieve substantially improved throughput from special purpose, parallel processing systems for multispectral data. The second area consists of a series of investigations directed at improving the machine processing techniques and our understanding of them. The third area is a series of programs with various investigators from user agencies to exploit the techniques developed to date in demonstration applications of practical interest to users, which also generally extend the usefulness of these techniques. Finally, the fourth area is improving experimental sensors for earth resources applications, both multispectral scanners in the 0.4 - 14 μm region and multispectral imaging radar with X- and L- bands.

In this paper I will summarize the status of these four areas of research, the activities of the past year in the area of improved throughput processing systems, and cite one result from the processing techniques improvement area. Four of the papers following this one by authors from the Willow Run Laboratories (WRL) will present results from this information extraction technique development area. As shown in Table I these are the papers by W. Malila, G. Suits, R. Nalepka, and R. Vincent. Results from the user applications of data processing will be presented in the paper by F. Thomson. Improved experimental sensors are discussed in the papers by P. Hasell and L. Porcello.

Eleven reports [Ref. 1 - 11] will be issued on the work of this past year, in addition to journal articles and papers. During the course of the paper, I shall refer to these reports so that those interested in details will have the references.

IMPROVED THROUGHPUT PARALLEL PROCESSING SYSTEMS

The assessment of current multispectral processing systems to meet the needs of keeping pace with multispectral data acquisition which occurs typically at rates of hundreds of kiloHertz or megaHertz is given in the table below:

1. Sensor capability exceeds processing capability by large factors

2. Digital and analog implementations of present techniques will not keep pace with needs of many operational-prototype information systems

3. Multiple computer approach may be too costly

4. Hybrid implementation of special purpose parallel processing with improved techniques appears promising from both throughput and cost aspects but requires development

Presently available conventionally organized digital computers are too slow (with current algorithms) by orders of magnitude so that even many computers per sensor are still inadequate. A parallel processing analog computer at Michigan meets the data rate requirement, but is slow to set up reducing the average throughput. Parallel processing all-digital computers may become useful and practical for image processing in the future but are not yet competitive. However, the programmability of the digital computer combined with the high throughput calculation rate of parallel channel analog computers in a hybrid multispectral processor, which we are beginning to build at the WRL with NASA support, appears to offer a realistic way now to breakup the processing bottleneck caused by data collection capability far outstripping processing capability in terms of both throughput and cost. Figure 1 indicates the present and projected multispectral data capability as various sensors begin to operate, [Ref. 12].

These are the Michigan multispectral scanner (M-5) and new Michigan single aperture scanner (M-7), the NASA 24-channel Multispectral Data System, and the ERTS-A multispectral scanner. The maximum planned rates are about 10-15 billion data elements per week.

Data quantities of this rate are impressively large but the cost to process the data is not well known. Some rough idea of the costs of data processing per element and per square mile are shown in Figure 2. The Corn Blight Watch multispectral processing costs using analog and digital computers separately were somewhere between $100 and $200 per square mile indicating the achievement of a feasibility type processor system. The impact of these costs can be assessed if some typical applications are analyzed. Some are given in Figure 3. The Corn Blight multispectral processing costs for 50 square miles were not $42,000/week but about $5,000 to $10,000 per week again indicating progress beyond research processor costs. The practical impact of cost reduction by proceeding to prototype or operational equipment is easy to project and will be quite dramatic. I feel that costs of a few dollars per square mile for processing are achievable. Using the projected data capacities and research processing costs of $420 per square mile, Figure 4 shows the cumulative cost picture where the continued rise in costs is the accumulated cost as various sensors are introduced and used. The 2 breaks in the cost curve in 1972 and 1973 indicate the cost leveling effect of the introduction of prototype processor at either of these points in time. Development of a prototype processor is expected to take two years, however.

We have investigated the possible design alternatives for such a prototype processor of the hybrid parallel processing type and are beginning its implementation. Figure 5 shows a component diagram for such a system which indicates the various types of units that are involved. Figure 6 indicates the various functions that are performed and some estimate of the time required in terms of factors of real time meaning acquisition rate for a typical multispectral scanner. One of the major variables which we need experience with to bring under control is the man-machine interaction with this type of processor. Some of the benefits derived from achieving such a prototype processor are listed below:

1. Facilitate research and development

2. Meets the needs of prototype data processing demands

3. Allows projection of operational costs

4. Defines operational requirements for personnel and equipment

5. Reduces present costs

It will facilitate further research and development, making it dramatically quicker and less costly to experiment with different techniques and applications. Because this parallel processor meets the needs of prototype data processing demands, projected data collection over the near future can be processed in a timely fashion. Projection of operational requirements and costs will be more accurate and present costs can be reduced. We see the hybrid as an improvement, not necessarily a breakthrough or panacea, but a needed improvement nonetheless. It may also speed the day of on-board processing for aircraft and satellites.

A particular point of view must be preserved: that of the information needs of the problem-oriented user. The fact that the user of such data is not directly concerned with the techniques or physical parameters of sensing and processing but is, rather, interested in mapping, identifying and studying specific objects on the surface of the earth and the interrelationships of these objects, must be foremost in the conception and implementation of these information systems. The user would like to know, for example, how many bushels of wheat and corn will be produced in a county of so many acres, how many ducks will be successfully raised in the prairies, how much water is needed to preserve the Everglades and where are and what are the various sources of pollution for Lake Michigan, Lake Ontario, or Chesapeake Bay.

Data processing, it should be noted here, refers to the procedures, algorithms, and computations which are applied to the raw sensor output data to transform it into useful information to the user. Data processing includes the combination of (1) data formatting, handling, editing, digitizing, or film printing with (2) data reduction and analysis consisting of image enhancement, spectral analysis, signature correlations, and recognition computations. Care in understanding the scope of data processing is required because the term can mean only (1) above, thereby leaving out data reduction, analysis and recognition (or classification) which are critical to the user as information extraction processes.

IMPROVED INFORMATION EXTRACTION TECHNIQUES

I would like to proceed now to summarize my assessment of the status of the 2nd area of activity in our program, namely processing techniques or information extraction techniques. The table below indicates the judgement that a variety of useful techniques have been demonstrated to be feasible in various applications under limited conditions appropriate to showing feasibility but not generally appropriate to prototype or pilot operational conditions.

1. Variety of techniques are feasible in many applications under limited conditions

    a. Constrained data collection to minimize effects of resolution, atmosphere, and changing illumination

    b. Little or no time constraint for processing

    c. Maximum ground observation

2. These limitations are being lessened to the point where operational-prototype information systems are feasible in some applications

This transferral of present techniques to prototype environments is needed and requires effort to solve problems which arise that are not otherwise evident. The Corn Blight Watch pressured conditions (1b) and (1c) in the table above by imposing a time constraint of less than one day per 10 square mile segment processed and reported and reducing the amount of ground data collected. Aircraft data collection costs can be reduced by relaxing the constraints on sun angles and cloud cover percentage presently imposed by processing techniques limitations.

Further technique development is clearly required. The thrust of our activities in this area has been the development of techniques that allow the reduction of required ground observations and that extend spectral signatures in space and time away from these known areas. The fundamental barrier to signature extension to large areas has been variations in the environment. These variations are manifested, both spatially and temporally, as changes in atmospheric transmission, illumination of the scene, bidirectional properties of the materials, and atmospheric path radiance or backscatter. The table below outlines several areas where we are working at improving processing techniques:

1. Extending the Applicability of Training Sets
2. Spectral Signatures and ERSIS
3. Modeling and Simulation
4. Ratio Processing
5. Parameter Mapping
6. Proportions of Classes
7. Adaptive Techniques
8 Mensuration and Mapping

Extending the applicability of training sets away from known areas has been studied previously at WRL using 3 approaches: (1) the use of preprocessing transformations on the remotely collected multispectral data aimed at reducing systematic variations; the intent of these transformations is to make the data invariant despite variations in transmission, illumination, and path radiance, (2) the use of ancillary sensors in the data collection platform such as the sun sensor to measure illumination, transmission, or path radiance variations, and (3) the use of in-scene references which provide a calibration in the scene that permit corrections to the data are all useful in signature extension and reducing the amount of ground observation required. This year we have extended these studies to modification of the decision parameters, decision rules, and adaptive classifiers.

We have continued our efforts to understand the basic spectral characteristics of various materials so that spectral signatures can be better understood and have added data to the Earth Resources Spectral Information System (ERSIS) installed on the Univac 1108 at the MSC which will aid other investigators in understanding the spectral reflectance, emission, or transmission of natural materials, in determining the spectral channels likely to be of interest in their application, or in devising an appropriate processing technique. Dr. David Pitts of the Earth Observations Division at the NASA/MSC has responsibility for user requests for laboratory or field spectral data in ERSIS.

ERSIS also provides basic data as input to models and simulations of various problems in remote sensing applications. Dr. Suits' model for predicting the directional reflectance from vegetative canopies given in a following paper is an example of the use of spectral reflectance data as an input to derive important insight. Our efforts in each of the other areas listed in the table above and the significant progress made will be discussed in papers following, except for the adaptive techniques area which I will turn to now.

ADAPTIVE MULTISPECTRAL PROCESSING

I would like to present one preliminary result of some interest from the work on adaptive classifier techniques by Bob Marshall, Frank Kriegler, and Wyman Richardson of our staff, [Ref. 13]. Figure 7 shows a comparison between two different classifiers recognizing wheat (shown as the darkest tones) in a 4 or 5 mile long agricultural scene. The map on the left half shows the result of using a single distribution (that from field A) in a maximum likelihood classifier to recognize wheat and shows a gradual deterioration in recognition over the run from bottom (South) to top (North). The reason for this deterioration was determined to be a change in illumination due to changeable atmospheric conditions. A simple algorithm to adapt the means of the distribution in an exponentially weighted fashion when points are recognized as wheat was added to the maximum likelihood classifier. The results of this adaptive multispectral processing are shown on the map on the right half. The improvement in recognition accuracy using this adaptive classifier is apparent.

Some increase in false classification occurs in two oat fields just below the two small wheat fields in the left center of the run. Since only the means of wheat were being adapted rather than all distributions some capture of the process by other distributions was expected and exists.

A simple experiment was also conducted to determine the ability of the algorithm to recover, given a transient error. The set of means obtained at the end of the run in field B were used as an initial estimate for field A and a classification run was made which is shown in Figure 8. No difference exists after 600 points, twice the weighting constant of 300.

While not all sources of error in classification are correctable by adaption those remaining after preprocessing transformations have reduced the systematic variations may be largely corrected. It appears that a considerable processing gain may be obtained from adaption of distribution parameters and we intend to pursue this vigorously. In terms of a digital classifier, the speed of classification may be improved as a direct function of the number of distributions eliminated from the classifier in exchange for a simple mean adapting computation. For analog and hybrid processors, the complexity and size of the machine may be reduced.

It is possible to relate the results obtained in modeling the scene and the radiative transfer in the atmosphere to the adaptive recognition process. This makes it possible to use models to describe the general trends for the trajectories of distributions and to make corrections as functions of the agreement between observed changes and the predicted trajectories.

PRACTICAL USE OF EXISTING TECHNIQUES IN USER APPLICATIONS

I now want to assess the status of the 3rd area of our program, user applications. It is the benefits in user applications which is the raison de etre of the entire Earth Resources Survey Program. As shown in the table below the potential of multispectral sensing and automatic processing has been demonstrated.

1. Many applications in a variety of user disciplines have been demonstrated to be feasible under limited conditions.
2. Operational-prototypes may be feasible in some applications from both technical and cost aspects
3. No operational use is yet being made of information

A large number of user applications of Multispectral Earth Resources Information Systems have been demonstrated to be feasible in scaled down programs and we are ready to examine ERTS data with confidence of what has been accomplished from aircraft. Some applications are further advanced than others and operational prototypes should be exercised next for some of these. However, no operational use is yet being made of any information system on Earth Resources employing multispectral sensing, I believe largely because they must become cost effective first.

IMPROVED SENSORS FOR EARTH RESOURCES APPLICATIONS

The status of multispectral sensors technology is assessed in the table below:

1. Improved experimental airborne MS scanners are now in use and the quality of data in the UV, visible, near IR, and thermal IR is generally excellent

2. Operational airborne MS scanners are commercially available

3. Spaceborne MS scanners will be utilized for the first time in ERTS and SKYLAB

4. Experimental airborne multispectral imaging radar is being developed

5. Experimental laser scanners are planned

The comments here basically indicate the mature and advanced state of this area. However, despite the attempts that have been made to date at systems engineering of complete information systems including user needs, sensors, and processors a more complete systems approach will be needed for multispectral sensing based information in the future.

CONCLUSIONS

Despite making substantial progress in achieving improved processing techniques, improved throughput parallel processing systems, improved experimental sensors for multispectral sensing, and showing the practical use of multispectral sensing in various earth resources applications, there is still much to be accomplished before the Earth Resources Survey Program spins off successful, operational user information systems. Potential benefits of information will remain largely "potential" until this is done.

The most critical need is for processing systems capable of keeping pace with the sensors so that unprocessed data does not have to be accumulated and stored. Greatly reduced costs of processing are also likely to result with an attendant increase in interest on the part of potential users.

But greatly reduced dependency on ground observations is also needed to reduce both the costs of collection and processing. For this reason continued research in pursuit of improved processing techniques which allow less ground data and multi-stage sampling approaches are required. Our signature extension and other information extraction technique development is aimed at this goal.

Spectral reflectance, emittance, and transmittance data on a great variety of natural materials are available to the remote sensing community through ERSIS. This data can be used to define the approach to many remote sensing problems by understanding the spectral basis of discrimination.

We are ready to examine ERTS and Skylab EREP data with confidence of what can be done from aircraft.

REFERENCES

(1) J. Erickson, "Research on Operational Earth Resources Information Systems Using Multispectral Sensing", 31650-89-P, in publication.

(2) W. Malila, et.al., "Information Extraction Techniques", 31650-74-T, in publication.

(3) W. Malila, "Discrimination Techniques Employing Both Reflective and Thermal Multispectral Signals", 31650-75-T, in publication.

(4) R. Nalepka, et.al., "Estimating Proportions of Objects From Multispectral Data", 31650-73-T, in publication.

(5) R. Vincent, "Rock-Type Discrimination From Ratio Images of the Pisgah Crater, California Test Site", 31650-77-T, in publication.

(6) V. Leeman, "NASA Earth Resources Spectral Information System: A Data Compilation, Supplement", 31650-69-T, in publication.

(7) V. Leeman, "NASA/MSC Earth Resources Spectral Information System Procedures Manual, Supplement", Informal Technical Report, 31650-72-T.

(8) R. Vincent, "Investigation of Theoretical Methods for the Optical Modeling of Agricultural Fields", 31650-78-T, in publication.

(9) F.J. Thomson & R.F. Nalepka, "Contribution to the Corn Blight Watch Final Report", 31650-104-L, January 1972.

(10) W.G. Burge, "Summary of Ground Observations of Selected Corn Blight Segments in Indiana", 31650-105-L, in publication.

(11) L. Larsen & P. Lambeck, "Performance of MSDS as of 18 August 1971", 31650-82-T, September 1971.

(12) R.E. Marshall & F.J. Kriegler, "An Operational Multispectral Surveys System", Proceedings of the 7th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, May 1971, 10259-1-X.

(13) R.E. Marshall, et.al., "Adaptive Multispectral Recognition of Wheat Fields", 31650-86-S, EAI Symposium on Automatic Photointerpretation, Washington, D.C., December 7-8, 1971.

TABLE I.- PAPERS IN THE UNIVERSITY OF MICHIGAN SESSION OF FOURTH ANNUAL EARTH RESOURCES PROGRAM REVIEW

IMPROVED PROCESSING TECHNIQUES

W. Malila	-	Information Extraction Techniques for Multispectral Scanner Data
G. Suits	-	Prediction of Directional Reflectance of a Corn Field Under Stress
R. Nalepka	-	Classification of Spatially Unresolved Objects
R. Vincent	-	Experimental Methods for Geological Remote Sensing

SHOW PRACTICAL USE IN USER APPLICATIONS

F. Thomson	-	User-Oriented Multispectral Data Processing at The University of Michigan

IMPROVED SENSORS

P. Hasell	-	Michigan Experimental Multispectral Scanner System
L. Porcello	-	Multispectral Imaging Radar

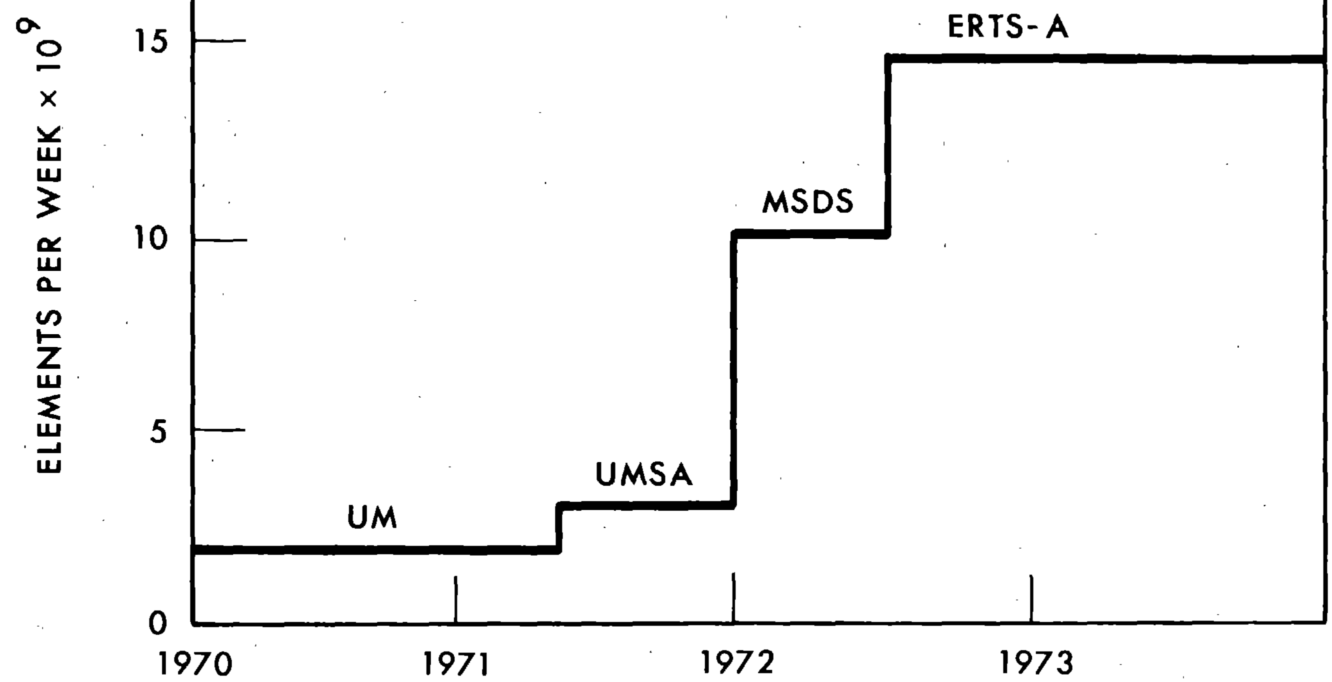


FIGURE 1. MULTISPECTRAL SCANNER DATA RATE CAPABILITIES

FIGURE 2. OPERATING COST OF PROCESSING

	\$/ELEMENT	\$/MI^2	HOURS/MI^2
RESEARCH	130×10^{-6}	420	2
FEASIBILITY	60×10^{-6}	195	1
PROTOTYPE	3×10^{-6}	10	0.05
OPERATIONAL	1×10^{-6}	3	0.02

JOB	AREA SIZE	RESEARCH PROCESSOR COST	PROTOTYPE PROCESSOR COST
SURVEY AGRICULTURAL COUNTY	36 sq. mi.	$15,000	$360
CORN BLIGHT SURVEY	100 sq. mi./wk.	$42,000/wk.	$1000/wk.
EVERGLADES SURVEY	4000 sq. mi./yr.	$1,680,000/yr.	$40,000/yr.
TYPICAL USER REQUEST	20 sq. mi./wk.	$8400/wk.	$200/wk.

FIGURE 3.

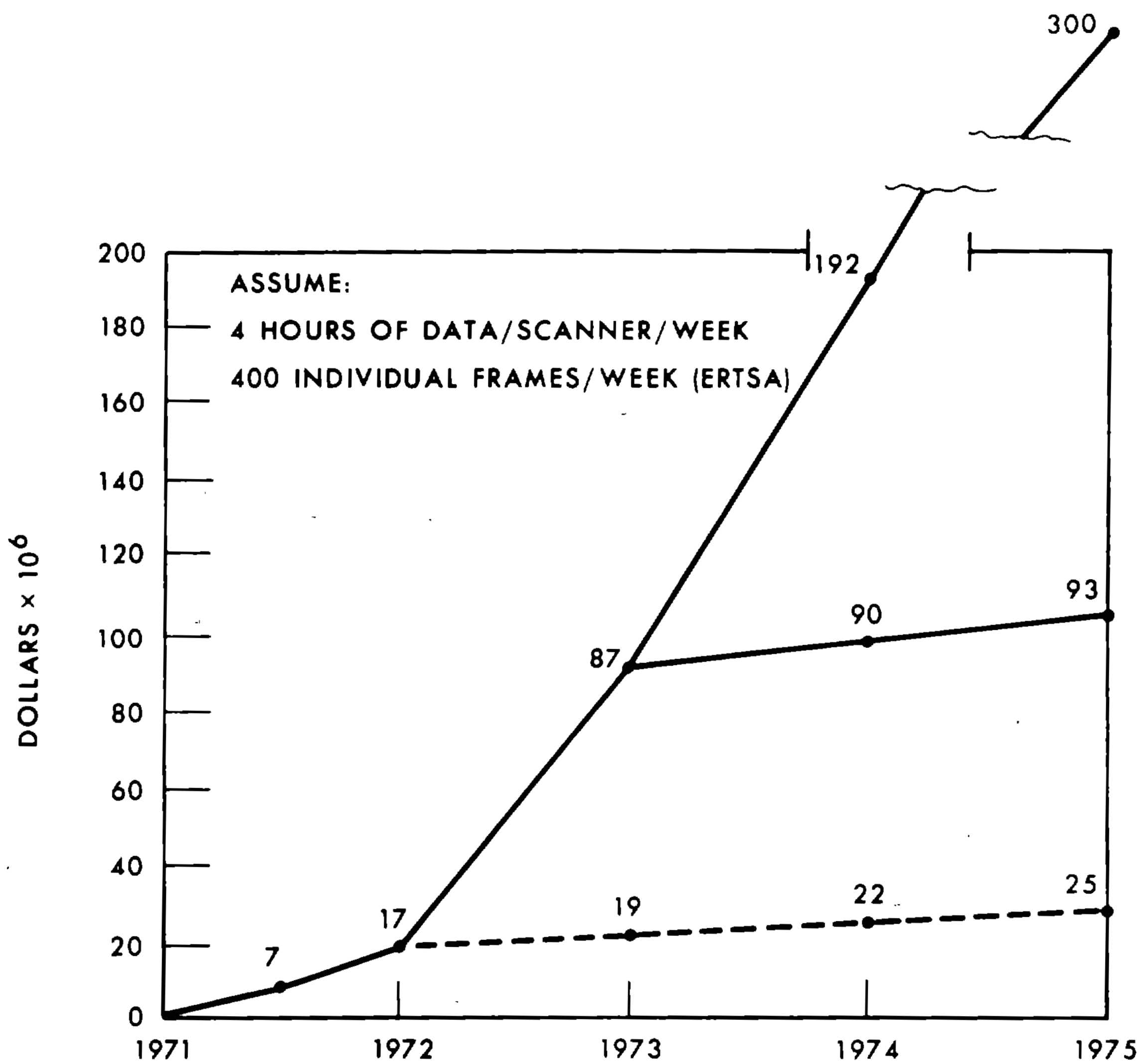


FIGURE 4. CUMULATIVE PROCESSING COST OF MULTISPECTRAL DATA

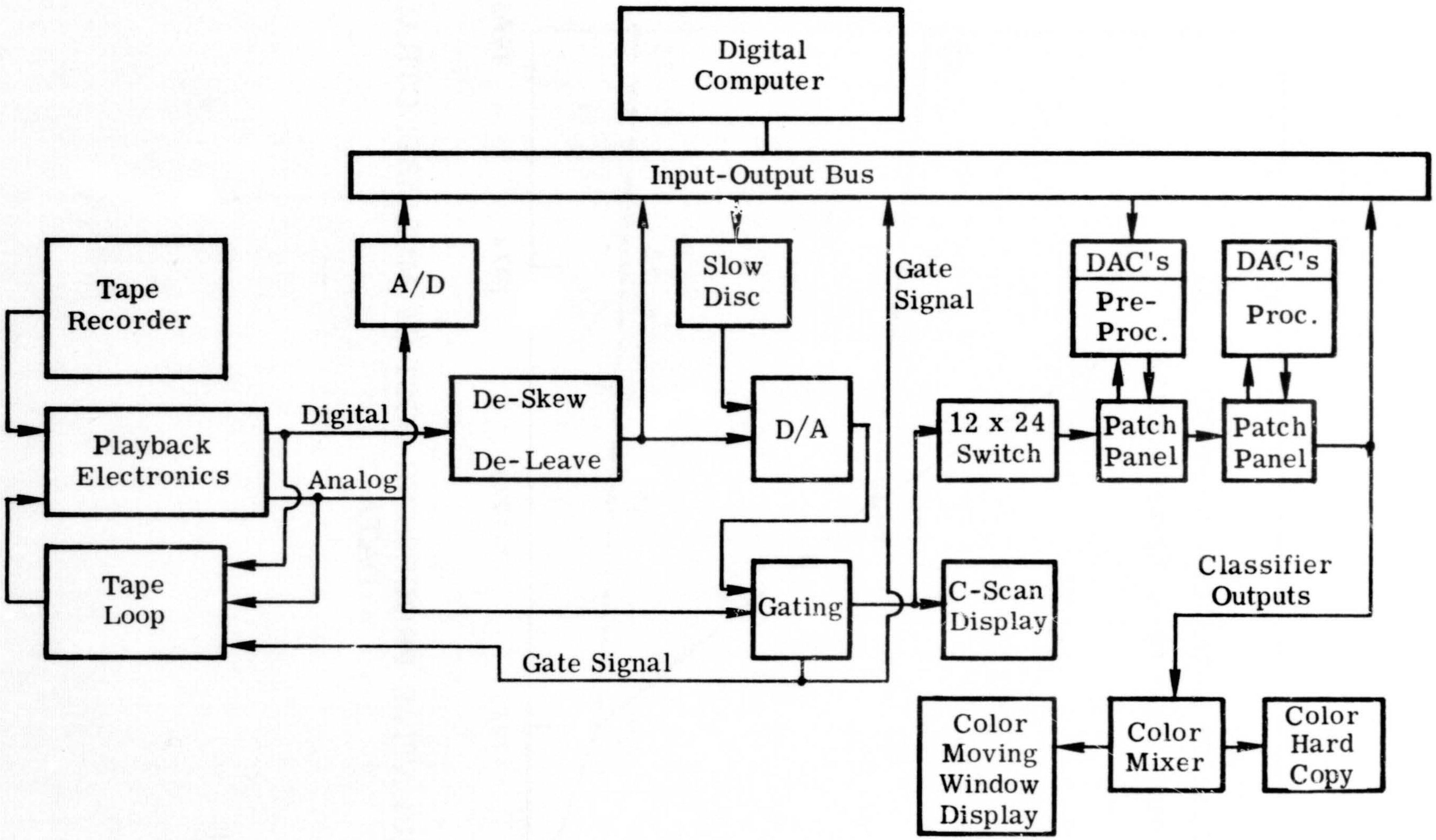
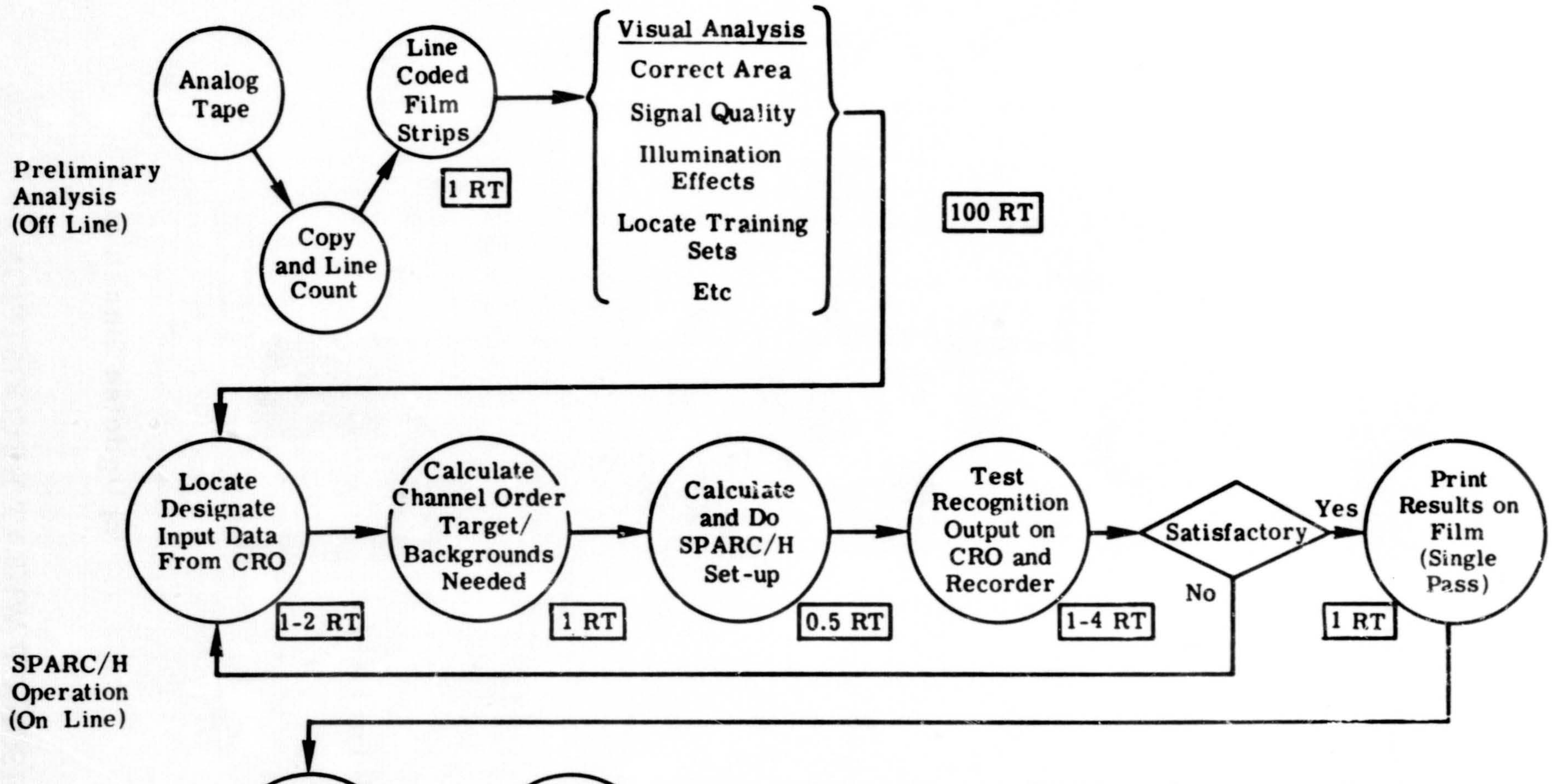


FIGURE 5. BLOCK DIAGRAM OF COMPLETE HYBRID PROCESSING SYSTEM



Estimated Rates:	SPARC/H	Total
For 12 Channel, 6 Distribution:	4 RT (1 hr)	125 RT (32 hrs)
For 6 Channel, 12 Distribution:	4 RT (1 hr)	125 RT (32 hrs)

(Rates are in terms of Real Time-RT, Times given are per 15 minute Tape Reel)

FIGURE 6. SPARC/H PROCESSING FLOW AND TIMING CHART

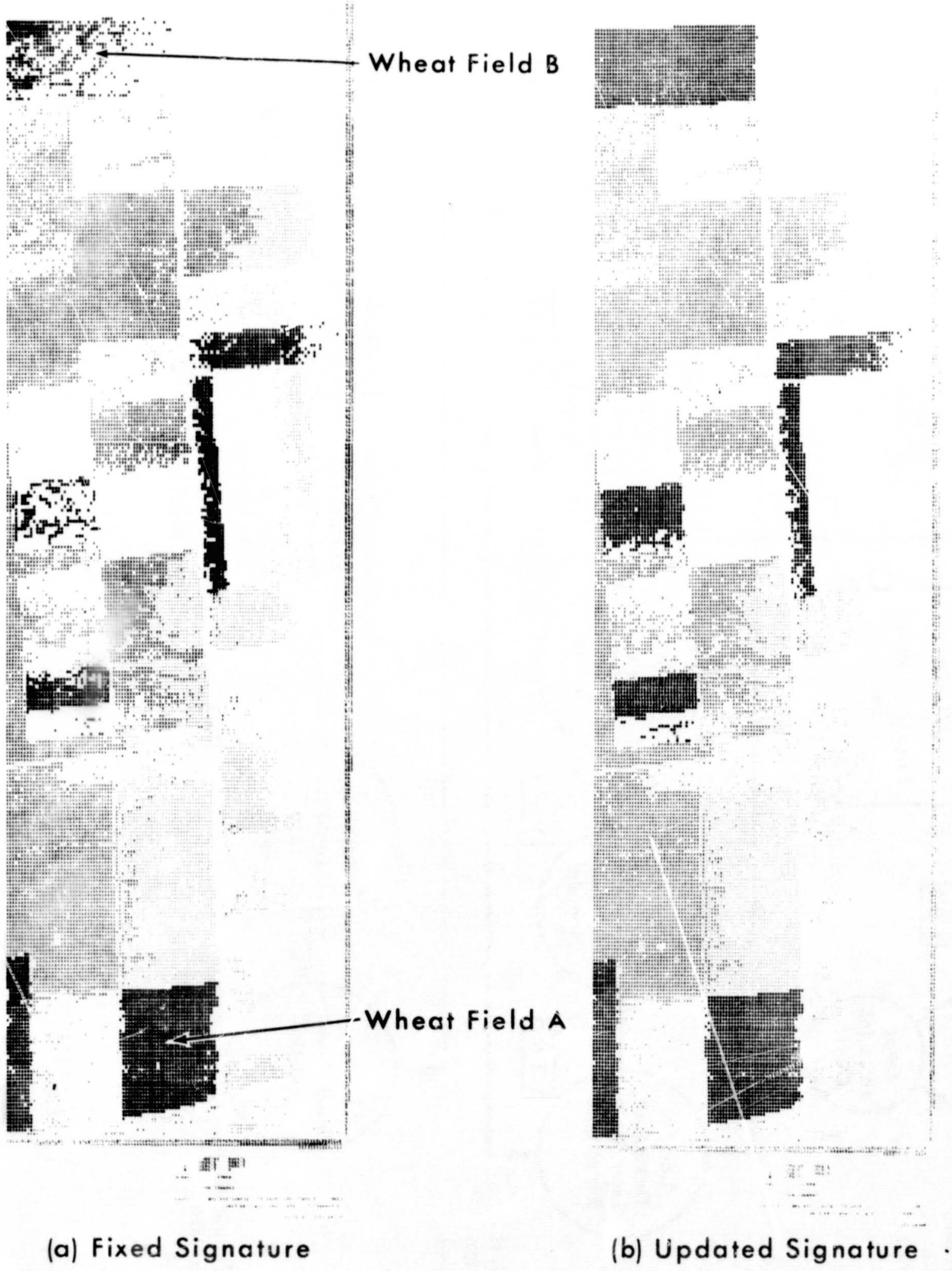
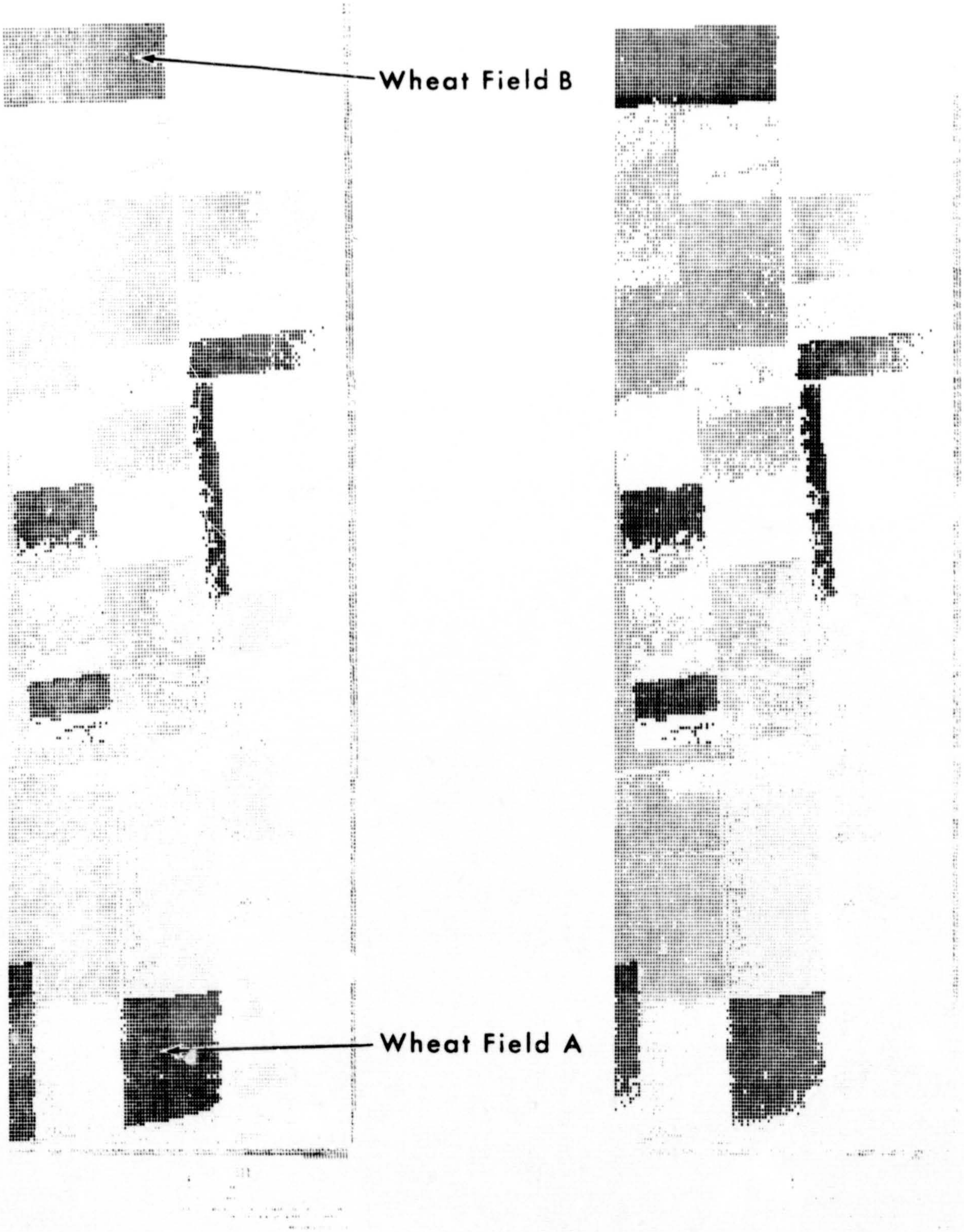


FIGURE 7. COMPARISON OF WHEAT RECOGNITION RESULTS FOR FIXED AND ADAPTED SIGNATURES



(a) Initial Signature From Wheat Field A

(b) Initial Signature Using Previous Update

FIGURE 8. WHEAT RECOGNITION RESULTS SHOWING THE CONVERGENCE OF THE ADAPTED SIGNATURE