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IMPLEMENTATION OF ILLIAC IV ALGORITHMS FOR MULTISPECTRAL IMAGE INTERPRETATION

Final Report

Robert Ray, Principal Investigator

June, 1974

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This report summarizes ILLIAC IV multispectral image processing research conducted during the last twelve months by the Center for Advanced Computation (CAC) of the University of Illinois in collaboration with the Laboratory for Applications of Remote Sensing (LARS) of Purdue University. The research reported has focused on the design and partial implementation of a comprehensive ILLIAC IV software system for computer-assisted

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20. Abstract (continued)

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IMPLEMENTATION OF ILLIAC IV ALGORITHMS FOR MULTISPECTRAL IMAGE INTERPRETATION

Final Report, covering the period March 1973-February 1974

June, 1974

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IV

ABSTRACT

This report summarizes ILLIAC IV multispectral image processing research conducted during the last twelve months by the Center for Advanced Computation (CAC) of the University of Illinois in collaboration with the Laboratory for Applications of Remote Sensing (LARS) of Purdue University. The research reported has focused on the design and partial implementation of a comprehensive ILLIAC IV software system for computer-assisted interpretation of multispectral earth resources data such as that now collected by the Earth Resources Technology Satellite (ERTS). Research to date suggests generally that the ILLIAC IV should be as much as two orders of magnitude more cost-effective than serial processing computers for digital interpretation of ERTS imagery via multivariate statistical classification techniques. The potential of the ARPA Network as a mechanism for interfacing geographically-dispersed users to an ILLIAC IV image processing facility is discussed.

Introduction

This report summarizes ILLIAC IV multispectral image processing research conducted during the last twelve months by the Center for Advanced Computation (CAC) of the University of Illinois in collaboration with the Laboratory for Applications of Remote Sensing (LARS) of Purdue University. The research reported focuses on the design and partial implementation of a comprehensive ILLIAC IV software system for computer-assisted interpretation of multispectral earth resources data, such as that now collected by the Earth Resources Technology Satellite (ERTS). This work has been undertaken in support of the earth resources monitoring objectives of the ERTS/EROS programs of NASA and USGS, and in support of the ILLIAC IV applications programs of ARPA and NASA at Ames Research Center.

Since its launch in July 1972, ERTS has demonstrated the practicality of orbital remote sensing systems as mechanisms for dynamic surveillance of natural resources and land uses at regional, state, and national scales.[1,2,3] From a sun-synchronous polar orbit 570 miles high, ERTS routinely telemeters to ground receiving stations high-resolution multispectral scanner (MSS) images each covering a geographic area one hundred nautical miles square. A single ERTS MSS scene consists of 7.6×10^6 digital image resolution elements (2340 scan lines and 3240 samples per line) yielding an effective ground resolution of about one acre. With eight bits of data recorded for each of four wavelength bands (two visible and two reflective infrared), each MSS image represents approximately 240×10^6 bits of data. Since these images are digitized at rates up to one every twenty-five seconds, ground processing, interpretation, and meaningful use of the data generated pose a number of challenging problems.

Computer methods of automatic image interpretation and information management offer promising means for reduction of the enormous data streams afforded by remote sensing technologies like ERTS into information convenient for regional, state, and national resource management agencies. For almost a decade now, research has progressed toward the application of statistical pattern recognition techniques within operational systems for automatic image interpretation.[4,5] To date, however, the sheer magnitude of the data processing required and the efficiencies of available computers have severely impacted the cost-effectiveness of such procedures outside research environments. The present research has been undertaken to determine the extent to which this condition is changing due to emerging information processing and communications technologies such as the ILLIAC IV parallel computer[6,7] and the nationwide ARPA Network.[8,9]

In this document we report research determinations to date concerning the efficiencies of multispectral earth resources data interpretation on the ILLIAC IV. Algorithms now operational on ILLIAC IV for analysis of ERTS MSS data are described, and execution times for these procedures are documented. General strategies are discussed for implementing data storage and retrieval systems, and interactive information management systems appropriate to ILLIAC IV image processing capabilities. Additionally, we discuss the potentials of the ARPA Network as a mechanism for interfacing a geographically-dispersed community of users to an ILLIAC IV multispectral image interpretation facility.

The Multivariate Analysis Approach to Earth Resources Data Interpretation

Procedures developed to date for ILLIAC IV interpretation of ERTS MSS imagery represent parallel-computation implementations of a subset of the multivariate analysis techniques previously researched at LARS in serial-computation mode for interpretation of multispectral earth resources data. (For an introductory mathematical description of multivariate methods of multispectral image interpretation as applied at LARS see SWAIN.[10]) The following verbal description of the methodology pursued for ILLIAC IV interpretations is offered in the interest of internal completeness for the present report.

The multivariate analysis methodology of multispectral image interpretation assumes that each earth terrain type of interest (agricultural, natural resource, land use, etc.) reflects, absorbs, and emits solar energies of various wavelengths in characteristic proportions. The model may be considered a highly sophisticated mathematical generalization of the process by which we recognize various landscape features according to color. Computer implementations seek to interpret entire images by independent classification of all image resolution elements into terrain categories according to the spectral data recorded for each element. Thus, while the output of such a procedure may be an interpreted terrain map, no spatial pattern recognition theory need be employed.

The methodology proceeds by representing all individual resolution elements within an image as independent, multivariate observations that may be grouped into meaningful terrain categories according to the multivariate distributions of spectral observations within each category of interest. Thus, the methodology assumes that the terrain categories to be recognized and mapped have spectral characteristics sufficiently dissimilar across the wavelength bands recorded that the multivariate distributions of observations within each category are statistically separable and distinct. Where terrain categories of interest have distinct spectral profiles, several approaches to computer-assisted image interpretation are possible.

The supervised classification approach assumes that all image resolution elements corresponding to particular terrain categories can be characterized with reference to the spectral properties of known samples of each terrain type. Given spectral characterizations for each terrain category of interest, resolution elements throughout an image are classified into terrain categories with reference to spectral properties alone. Statistical classification theory may be conveniently employed. Given ground truth information identifying fixed sets of resolution elements representative of each terrain category of interest, statistics are computed to estimate the multivariate distribution of spectral properties for all resolution elements corresponding to each terrain type. An entire image may then be automatically interpreted in point-by-point fashion by statistical classification of each image resolution element in accordance with the maximum of the discriminant function values computed for all terrain categories.

An alternative approach to computer-assisted interpretation relies on multivariate cluster analysis of image resolution elements. Following this approach, resolution elements comprising an area within an image are analyzed with respect to spectral properties, and assigned to data clusters such that image elements within each cluster have similar spectral properties while elements of different clusters have dissimilar characteristics. Since the multivariate methodology, in general, presupposes the existence of distinct spectral profiles for terrain categories of interest, there should exist some simple correspondence between resulting clusters and terrain types. A particular terrain classification schema is established in an a posteriori fashion by relating cluster analysis results to available ground truth information. Since, by this method, no a priori classification schema is assumed for machine categorization of input data, the cluster analysis approach may be considered an unsupervised classification strategy.

Multivariate statistical classification and cluster analysis techniques may be employed in a variety of ways together within computer-assisted multispectral image interpretation. Even where terrain categories to be recognized are prespecified and ground truth information has been collected as training data for supervised classification, training samples may be cluster analyzed first to determine the existence of multiple spectral profiles for image elements of single nominal categories.

A combination of cluster analysis and classification methods is also advantageous where data is to be interpreted that corresponds to large regions for which little is known about the spectral distinctness of terrain types. A systematic sample of all data may be cluster analyzed to determine spectrally separable terrain clusters. Using statistics computed for such clusters, all resolution elements within the region may be classified into the terrain types represented by all clusters. Once such a classification is mapped, a correspondence between the spectrally determined clusters and specific terrain categories can be established.

ELLEFSEN, SWAIN, and WRAY[11] used such a combination of cluster analysis and classification methods at LARS and have reported some success in producing large-scale regional land-use maps for the San Francisco Bay area from ERTS MSS data. Eight urban terrain categories and three bordering nonurban terrain types were identified and mapped with considerable accuracy. Results of smaller test analyses conducted at CAC using the same ERTS data tend to conform to LARS results with respect to identifiable terrain categories.

ILLIAC IV Efficiencies for Multispectral Image Interpretation

Due to the central roles of the statistical classification and cluster analysis algorithms within the LARS methodology of multispectral image interpretation, parallel-computation implementations of these two procedures have been developed at CAC to provide basic ILLIAC IV analysis capabilities with which the efficiencies of the ILLIAC IV for multispectral image processing can be evaluated. While both procedures involve very large amounts of computation for only modest quantities of multispectral data, both algorithms have parallel structures and hence their implementations on ILLIAC IV prove quite efficient. The fact that 32-bit arithmetic operations are sufficient for numerical accuracy within both of these algorithms makes possible additional efficiencies for ILLIAC IV executions.

The multivariate cluster analysis algorithm employed at LARS follows the ISODATA technique of BALL and HALL[12,13] with modifications similar to those suggested by SWAIN and FU.[14] A description of the algorithm as currently implemented at LARS can be found in SWAIN.[10] The ILLIAC IV implementation of this algorithm has been documented by THOMAS.[15]

The point-by-point classification methodology used by LARS represents a straightforward application of the maximum likelihood decision rule of statisical classification theory, assuming multivariate normal distributions for image elements within each category. SWAIN[10] describes the LARS implementation of this statistical classification technique. THOMAS[16] documents the corresponding ILLIAC IV implementation of this decision rule for ERTS data interpretations. Efficient utilization of the parallel structure of ILLIAC IV calculations is achieved by classification of 128 image resolution elements simultaneously.

To evaluate the potential efficiencies of ILLIAC IV multispectral image interpretations with respect to both the cluster analysis and classification algorithms, comparative tests have been made between ILLIAC IV execution times, and times reported by the IBM 360/67 of LARS, the DEC PDP-10 of the Information Sciences Institute (ISI) at Marina Del Rey, and the ILLIAC IV simulation system of the Burroughs 6700 at the University of California at San Diego.

Both simulated and actual ILLIAC IV timings were obtained for these experiments since the currently available execution timing mechanisms of the ILLIAC IV itself were not sufficiently accurate for meaningful comparisons where only a few seconds of execution time were involved. Comparative PDP-10 times were obtained to indicate the relative speed of backup ERTS data interpretation on the PDP-10 processors associated with the ILLIAC IV system at Ames Research Center and other interactive PDP-10 computers elsewhere on the ARPA Network. The LARS 360/67 computer was selected for comparison since it represents a facility dedicated to multispectral image processing. Also, LARS output could be used to validate the correctness of all other analysis results.

Earlier, RAY and THOMAS[17] reported the results of comparisons between ILLIAC IV simulation timings and actual execution times of the ISI PDP-10 and the LARS 360/67 for both cluster analysis and classification algorithms. As a test data set, a 64-line by 64-column rectangle of 4096 data samples was chosen within the ERTS San Francisco Bay image #1003-18175. A smaller rectangle of 1280 data samples was taken within this test area as a data set for the cluster analysis comparisons. Corresponding classification algorithms were executed on all three computers for the complete test area of 4096 samples. Fortran algorithms were run on the PDP-10 and 360/67 computers. Both ILLIAC IV algorithms were programmed in ASK. A summary of the results of these experiments is presented on the following page.

Table 1. Simulated ILLIAC IV, PDP-10 and 360/67 Execution Times

	ILLIAC IV	PDP-10	360/67
Cluster Analysis			
CPU Time (secs)	0.029	38.43	14.31
ILLIAC IV Speed Factors		1325	493
Classification			
CPU Time (secs)	0.0068	46.80	9.54
ILLIAC IV Speed Factors		6882	1403

Since actual ILLIAC IV execution times for these tests were too small to be clocked, larger test data sets were selected for comparison of ILLIAC IV and LARS 360/67 computations. Within the same ERTS MSS image, a 256-line by 512-column test area of 131,072 resolution elements was selected for classification. (See Figure 2.) A 1/16 systematic sample of 8,192 resolution elements taken every fourth line and every fourth column throughout the test area was chosen for cluster analysis comparisons. After cluster analysis of the sampled data of 8K elements into thirty-two clusters, all 131K resolution elements of the test area were classified into the corresponding thirty-two categories. Summary results of these experiments are presented below.

Table 2. ILLIAC IV and 360/67 Execution Times for ERTS Data Cluster Analysis and Classification

	ILLIAC IV	360/67
Cluster Analysis		
CPU Time (sec)	25($\pm$2)	3602
Classification		
CPU Time (sec)	6($\pm$2)	1464

Again, ILLIAC IV classification of core memory-contained ERTS MSS data is too fast to be meaningfully clocked with existing timing mechanisms. The results obtained, however, would indicate an ILLIAC IV-360/67 speed factor for classification closer to two orders of magnitude rather than the three orders of

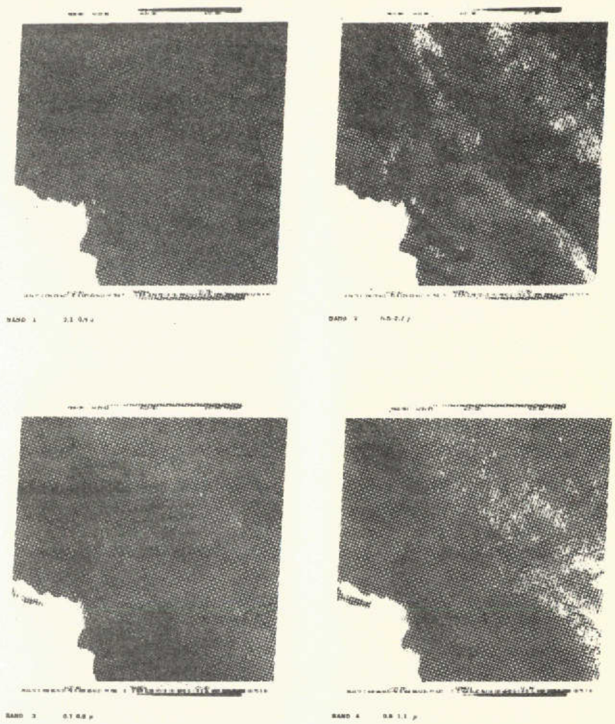

Figure 1. Photo reproductions of the four spectral bands of ERTS-1 image #1003-18175 selected as a test data set for ARPA Network-ILLIAC IV system development work. This imagery was taken over San Francisco Bay on 26 July 1972.

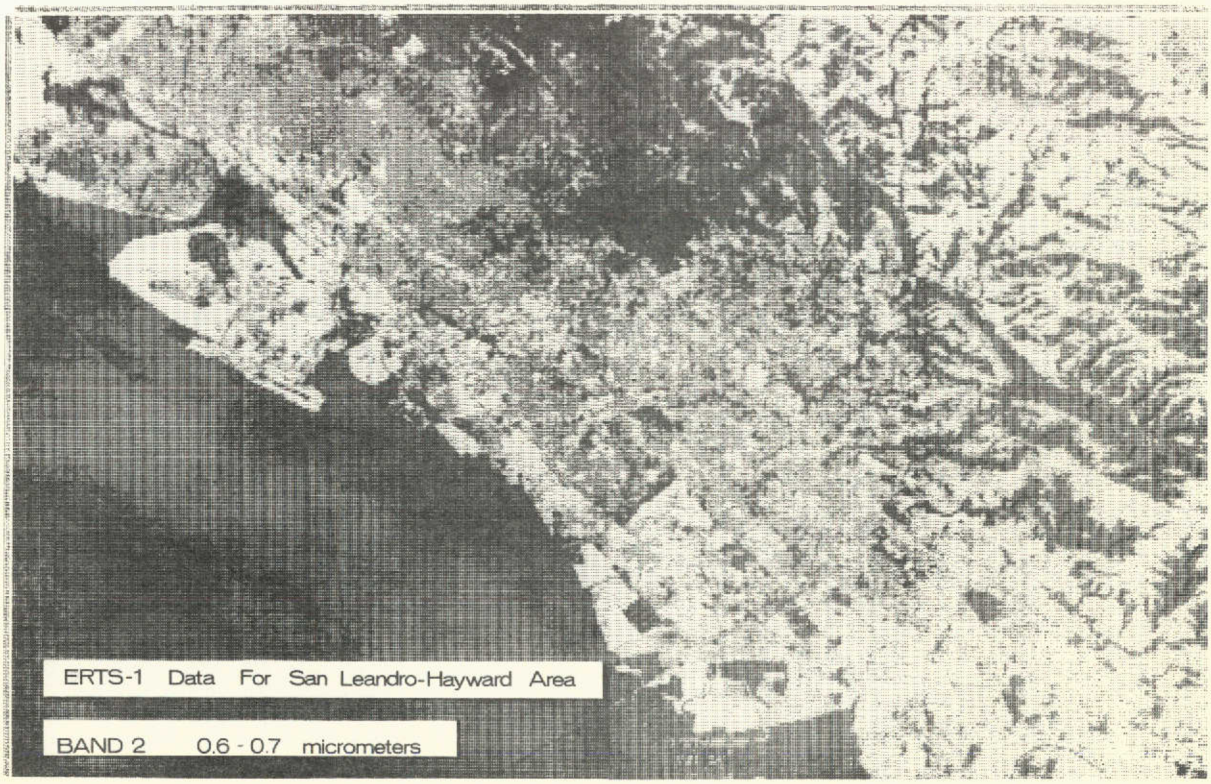

Figure 2. A line printer gray-scale display of the 256-line by 512-column image area selected for comparison of the ILLIAC IV and IBM 360/67 execution times for both the cluster analysis and statistical classification algorithms.

magnitude suggested by the simulation timings. Similarly, the results of the larger cluster analysis comparison would indicate an ILLIAC IV-360/67 speed factor on the order of only 144. We explain the discrepancy between actual factors and factors derived through simulation in the following manner: our simulations assumed ILLIAC IV operation in instruction overlap mode at an internal clock rate of 16 megahertz; the reported analyses were executed at 12 megahertz without instruction overlap. (The speed of the cluster analysis algorithm as programmed is more sensitive to the absence of instruction overlap due to the large number of data exchanges, i.e., routes, between processing elements.) As instruction overlap operation mode and greater internal clock rates become available for ILLIAC IV application programming, we expect actual and simulated execution timings for these two algorithms to be more in agreement.

Remote Multispectral Image Processing via the ARPA Network

Within the scope of activities summarized in this report, considerable research has been conducted at CAC during the last twelve months to assess the potentials of the ARPA Network as a means to decentralize ILLIAC IV image processing capabilities, and to share the resources of ERTS data analysis systems now being developed. For almost all computational support for research activities, CAC relies on the variety of computing facilities accessible to it remotely via the ARPA Network. Of wider concern is the fact that almost all access to ILLIAC IV image processing capabilities for all users will be provided by the network. Hence, we summarize here CAC networking experience within present image processing activities.

Concerned initially with the development of basic software for simulation of alternative ERTS data management and processing systems that might be implemented at Ames Research Center using the UNICON Data Computer and peripheral PDP-10 processors in conjunction with ILLIAC IV processing, CAC has developed an interactive ERTS data analysis system that is now operational on a number of PDP-10 computers on the network.

Designed to be addressed through low-cost portable computer communications terminals, the system allows interactive selection of rectangular image analysis windows from ERTS data tapes, gray-scale display of the raw data within these windows, interpretation via both cluster analysis and classification techniques, and printed character display of interpreted windows. Such interactive windowing allows convenient delineation of image resolution elements corresponding to areas of ground truth information. Windows may also be retrieved as systematic geographic samples of larger rectangular ground areas. The nature of portable terminals restricts use of the system to small scale data analysis. On the other hand, sufficient features have been incorporated into the system that the Statistical Reporting Service (SRS) of USDA plans to use the system experimentally to analyze small areas within ERTS images corresponding to agricultural test areas already established for SRS remote sensing research. SRS will access the ARPA Network through the node facilities of the National Bureau of Standards in Gaithersburg, Maryland.

Considerable experience has also been gained with network transmission of larger quantities of ERTS MSS data. Raw and interpreted ERTS data files on the order of 5 megabits corresponding to line printer displays approximately 3' by 5' are now routinely transmitted between sites on the network in less than fifteen minutes. This experience suggests that where terminal facilities permit, multispectral image processing can be accessed remotely over the network with essentially RJE terminal convenience.

Access to the ILLIAC IV and numerous other computational facilities via the ARPA Network has allowed CAC to develop considerable experimental software for graphical display of raw and interpreted ERTS MSS data. Using remote processing and terminal output devices at CAC, software has been developed for gray-scale line printer displays of ERTS imagery and geometrically corrected line printer maps of ERTS data interpretations. Experimental drum plotter software has been developed for plotting interpreted ERTS data maps at scales corresponding to USGS 7 1/2 minute quadrangles. Additionally, a modest research effort has involved interactive display of raw and interpreted ERTS data on CRT devices at CAC. (See Figures 1-6.)

Recommended ILLIAC IV Multispectral Image Analysis Systems

Experience with the LARS cluster analysis and statistical classification algorithms has indicated that ILLIAC IV batch interpretations should be close to two orders of magnitude more cost-effective than comparable processing on the other large-scale computers.

Experience with portable terminal, line printer, plotter, and CRT graphics software now developed at CAC for ILLIAC IV-ARPA Network multispectral image processing has demonstrated the potential of the network as a mechanism for decentralizing access to ILLIAC IV data analysis capabilities.

Therefore, we recommend continued research and development of more comprehensive ILLIAC IV multispectral image analysis systems. Research to date suggests that work in the immediate future is warranted in the following areas:

Using the UNICON Data Computer and the PDP-10 peripheral computers of the ILLIAC IV system, software should be developed for remote interactive maintenance and manipulation of the numerous data files associated with multispectral image interpretation. Additional software should be developed for

Figure 3. A line printer display of a portion of the test area interpreted by the ILLIAC IV using the cluster analysis and statistical classification algorithms. Here, the interpreted data has been geometrically reformatted to allow direct overlay of computer print-out with U.S.G.S. quadrangle maps of the same geographic area.

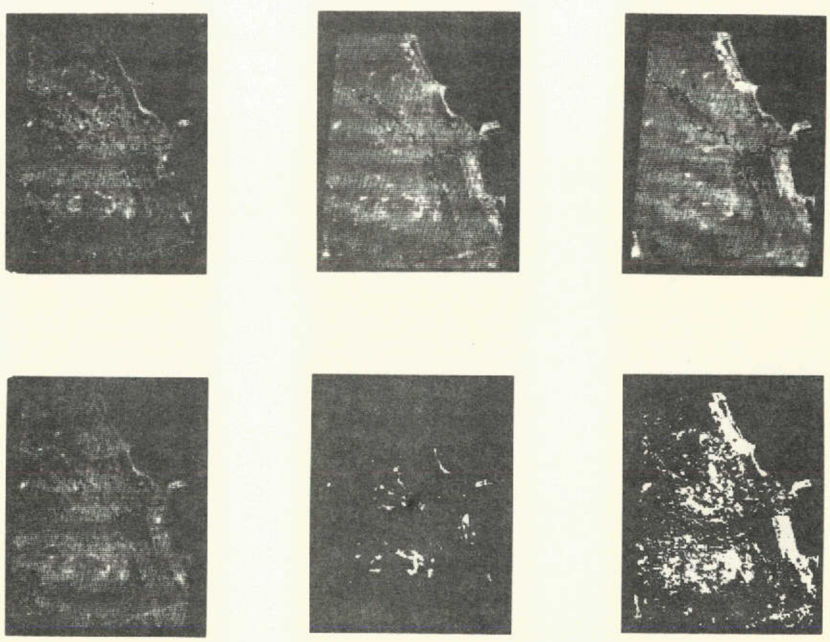

Figure 4. Example Polaroid photos by ERTS-1 data displayed on an IMLAC CRT device at CAC. The data displayed corresponds to the Chicago Loop area visible in ERTS-1 image #1007-16093. The bottom-right photo represents a color-coded interpreted data map achieved using digital color separation techniques and multiple color film exposures.

Figure 5. The Hayward quadrangle of the U.S.G.S. 7 1/2' topographic map series. The geographic area of this map falls completely within the test area chosen for ILLIAC IV analyses. (See Figure 2.)

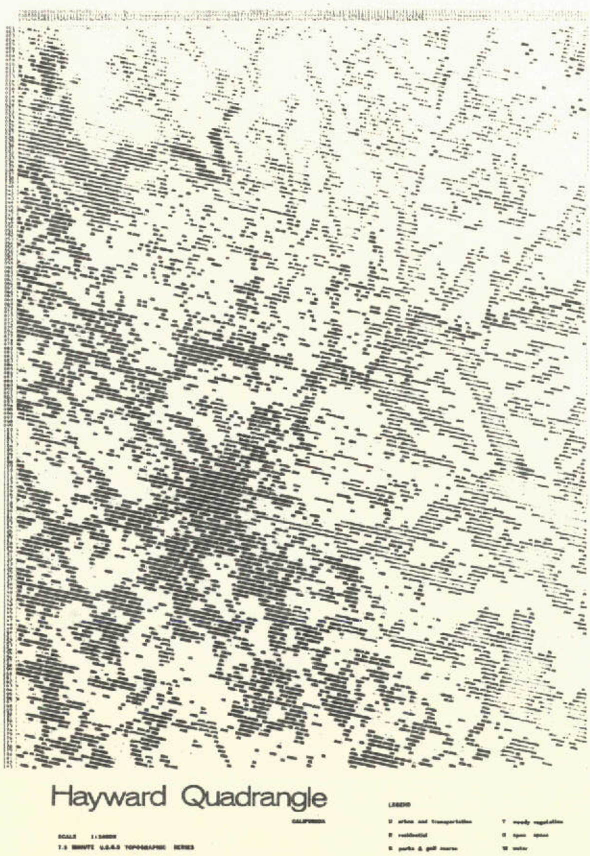

Figure 6. A computer-generated map showing current predominant terrain types for the Hayward quadrangle area. The map displays ERTS-1 data that has been interpreted on the ILLIAC IV and processed further for color mapping using the Zeta drum plotter at CAC.

interactive retrieval and display of portions of imagery corresponding to analysis areas conveniently specified by users in terms of latitude and longitude boundaries. Using low-cost portable terminals and pen digitizers, interactive software should be developed for convenient specification of matched control points between multispectral images and maps, thus facilitating accurate geographic registration of archived data. Given accurate geographic referencing of data and interpretations, other systems could be implemented for interactive pen-to-image or pen-to-map information retrieval, delineation of ground truth training sample areas, and occasional digitization of irregular, geographic networks and boundaries for display within raw and interpreted data maps.

Comprehensive ILLIAC IV software should be developed for drum plotter and film scanner display of multispectral data interpretations in map format. Included should be capabilities for plotting, at any scale, color-interpreted maps of any north-south rectangle within an image. Emphasis should be placed on plotting terrain maps equivalent with respect to area, scale, and map projection to USGS topographic maps of the 7 1/2', 15', and $1^{o} \times 2^{o}$ quadrangle series.

ILLIAC IV system capabilities should be implemented for aggregation of interpreted data in cellular subdivisions by various geographic referencing systems, including latitude-longitude, UTM, square kilometer, and square mile units. System capabilities for accurate registration of imagery with base maps and for aggregation of data interpretations by grid locations will then allow efficient computer analysis and display of regional land use and natural resource boundary changes over time.

As time and resources permit, other research should concern developments and implementation of additional ILLIAC IV algorithms for multiple image registration and terrain classification with respect to seasonal change. Additional research should explore the problems and advantages associated with ILLIAC IV analysis of digitized U-2 film imagery as supplementary, high-resolution multispectral data sources.

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