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APPLICATION OF ADP TECHNIQUES TO MULTIBAND AND MULTIEMULSION DIGITIZED PHOTOGRAPHY[1]

by

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ABSTRACT

Automatic data processing (ADP) techniques using a digital computer for data handling and analysis have allowed quantitative examination of aerial photography. Scanning microdensitometer techniques were utilized to digitize both multiband and multiemulsion photography. This digital density data from 1:120,000 scale aerial photos were spatially registered by computer and then analyzed, using statistical pattern recognition algorithms. The feasibility for automatic recognition of several cover types is indicated. Similar results were obtained from the digitized multiband and multiemulsion photographic data.

INTRODUCTION

As any photo interpreter knows, tone is one of the most significant factors used in the interpretation of an aerial photo. Tone allows one to distinguish between various objects and, due to differences in tone between objects and their background, one can determine the size and shape of objects. Variations in tone give materials their various appearances of texture.

When working with large-scale photography of forest or agricultural areas, tone is probably less important than size, shape, texture, etc. in identifying an object, because the shape of a tree crown, for example, can be readily determined on such large scale photos; however, as one progresses to smaller scale photography, the spatial resolution becomes less important and variations of tone become more important in distinguishing and identifying

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various objects. This is particularly true in the interpretation of small-scale aerial photos for agricultural purposes, when one must rely primarily on tone and pattern. The pattern and tonal differences can show where the agricultural area is located, and the pattern and size of fields can give some indication of soil conditions. In some specialized situations, such as viewing contour farming or rice paddies, shape and size of the fields allow many important inferences; however, it seems reasonable to say that the shape or size of an agricultural field often gives no indication of the crop species or of the condition of the species. Satellite or small-scale aerial photos such as the 1:120,000-scale photos shown in Figure 1 illustrate this point; various tones are obvious but the crop species or conditions cannot be determined by other photo interpretation factors such as shape, size, pattern, etc. Thus, the photo interpreter using such small-scale photos must rely heavily upon tonal differences to identify the various agricultural materials and other conditions or features of significance.

In the past few years, a number of photo interpreters have become increasingly interested in the significance of subtle variations in tone on photos (5, 8, 10, 12). For example, small tonal changes have been shown to be related to incipient disease infestations in vegetation (4, 7). Studies using satellite photography to identify various agricultural crops and other materials have also been based primarily upon tonal variations (2). Thus, proper interpretation of tonal variations has become increasingly important. Subtle changes in tone on small-scale photos are often difficult to delineate and interpret qualitatively, particularly when attempting to identify different species and conditions of crops. Interpreters have therefore become more and more interested in the possibility of analyzing aerial photos using quantitatively determined variations in tone as major criteria for identification of cover types, species, or conditions of significance.

This study was conducted to (1) study the problems associated with accurate measurements of film density, (2) study data handling techniques (such as spatial registration of multiband data) required for quantitative analysis of digitized photography, (3) show the feasibility of automatic cover type identification based on digitized photographic data, and (4) compare some results obtained from multiband and multiemulsion data analyses.

MULTIBAND AND MULTIEMULSION PHOTOGRAPHY

Two techniques, both of which produce photography suitable for quantitative evaluation, have been commonly used to obtain small-scale aerial as well as satellite photography. The first technique simply involves obtaining color or color infrared film, which we will refer to as "multiemulsion photography." Such photos incorporate three different emulsion layers, sandwiched together into a single photograph, each layer of which is sensitive to a different part of the spectrum. The second technique involves the use of different films and filters for photographing the same scene in several wavelength bands and producing a separate black and white emulsion photo for each band. We will refer to this method as "multiband photography".

Figure 1 shows a set of multiemulsion and multiband photography. These are 1:120,000-scale aerial photos obtained by NASA's RB-57 from a 60,000-foot altitude. Figure 1-a is a color infrared photo (containing three emulsion layers and thus referred to as a multiemulsion set of data). Figures 1-b, 1-c, and 1-d are separate black and white photographs, each obtained by a different camera and each representing the same area in a different part of the spectrum. The three together represent a set of multiband photography. The S065 experiment of Apollo IX is a prime example of satellite data collection using both multiemulsion and multiband photography, examples of which are familiar to many people.

It should be pointed out that multiemulsion photos are limited to three emulsion layers in the manufacturing of the film, but multiband photography can involve several wavelength bands. Considerable research has been conducted with 4 to 9-lens camera systems (8, 12), and even sets of 16 multiband photos have been utilized. Experience has shown, however, that the human photo interpreter can easily become inundated with imagery when attempting to work with 16, 9, or even 6 multiband images of the same area. Yet the subtle tonal differences between the various wavelength bands of imagery are often very important in using and interpreting such imagery. Clearly, there exists a need to quantize the tonal characteristics of the photos so that computerized analysis techniques, capable of handling several wavelength bands simultaneously, can be utilized.

DENSITOMETRY TECHNIQUES AND PROCEDURES

To quantize the tonal variations on a photograph, film density measurements are obtained. Such measurements can be carried out on a wide variety of commercially available densitometers. These devices use a light source and an optical system to direct illumination through a minute portion of the film, and a photoelectric sensor is used to measure the transmitted light. The illuminated spot can vary considerably in size (i.e. 0.001 to 0.125 inches). The ratio of the incident light to the transmitted light is called the opacity and the film density at that spot is defined as the base ten logarithm of opacity. Thus a perfectly transparent area in the film has an opacity of 1 and a density of 0. A spot transmitting only 1/1000 of the light has a density of 3. Densitometers compute the density and then output the value in one of several forms, such as a dial indicator, a punched paper tape, tape recorder, or other storage media.

Two rather different methods have been most frequently used to quantize the film density. The first involves a measurement at individual, manually controlled points on the film. However, this technique can become rather cumbersome if large numbers of points are required to achieve statistical reliability. A second method of quantizing film density has been of great interest to many photo analysts. This technique utilizes a scanning microdensitometer, which scans and measures the density of many small adjacent lines in sequence. This permits a film density measurement of many minute areas over the entire frame of photography to be obtained.

The three most common types of scanning densitometers are: (1) the moving table, (2) the rotating drum, and (3) the cathode-ray tube (CRT). Table type units use precision microscope optics and achieve density accuracies of .1%, or better. Rotating drum devices achieve good accuracy, in the order of 1-2%, and offer high speed scanning capability. CRT or vidicon units offer even higher speeds but tend to be less accurate.

A rotating drum unit, shown in Figure 2*, was utilized in our research. This system has a spatial resolution of from .001" to .004" and density accuracy of about 2%. The unit scans transparencies via a rotating drum on which the film is mounted. The arrow, in Figure 2, points to this scanning drum. A light source and optical system are used to project a beam through the film, and a photo cell mounted below the drum senses the transmitted light. The film is scanned in the Y direction through the rotation of the drum and in the X direction by a lead screw which moves the optical head down the drum. The electrical signal representing the transmitted light is sampled and converted to numerical form on a logarithmic scale. The digital density samples are then written on magnetic tape for future processing. Density readings are recorded with an accuracy of 2^8; thus zero density is represented by a 0 and level 3 density is represented by the number 255. A device of this type allows one to accurately transform the film to a numerical data format.

The three 70 mm B&W multiband photos were reproduced as positive transparencies which could be scanned directly with the microdensitometer. However, before the color infrared multiemulsion photo could be densitometered, it had to have the three emulsion layers separated and reproduced as black and white positive transparencies. This was accomplished by a standard commercial process using No. 49 blue, No. 60 green, and No. 25 red filters. Other more direct methods of achieving color separation can also be used. The advantages and disadvantages of these methods will be discussed later.

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* The device pictured is an Optronics Inc. P-1000 digitizing, rotating-drum microdensitometer.

As an indication of time required and the amount of resultant data, in this study the B&W multiband transparencies were microdensitometered using .001 inch resolution. Each 70 mm frame required 40 minutes to scan, and each scan produced over four million density measurements.

DATA HANDLING OF DIGITIZED PHOTOGRAPHY

After the film density data was recorded on magnetic tape all subsequent processing was done on a digital computer. A key problem in working with such digitized imagery is to reproduce a pictorial representation that will allow a human to interact with the data on the computer tape. The LARS Digital Video Display Unit shown in Figure 3 has proved very effective for interfacing with digital data. This device reads data from the data storage tape via the computer, rapidly converts the numbers to voltage form, and feeds this signal to a standard television monitor. The image it creates consists of 768 points per line, 525 lines, and is refreshed 30 times a second. The keyboard and typewriter at left of Figure 3 are used to control program execution and display functions. The light pen is used to select coordinates of points in the image. The system also includes a slave photocopy unit for making photo copies of the displayed image.

Another way of reproducing an image from digital data is through a computer line-printer gray-scale printout, as shown in Figure 4. A set of ten standard characters is used to reproduce the gray scale, from M for the darkest to a blank for the brightest. On the left in Figure 4 is a photograph taken on the digital display photocopy unit of the digitized multiband photo in the .59-.71 μm wavelength band. The line printer image represents all the points inside the bordered area indicated. The fact that the data consists of individually digitized points is emphasized in the line-printer display. These two methods allow either on-line and off-line image reproduction of digitized photographic data. Human interaction with data in the image is achieved via the light pen for the on-line digital display and by observing the line and column number of the selected point on the line-printer, or off-line, image.

As an indication of the quality that can be obtained for digitized photographic data, Figure 5 shows the .59-.71 μm color separation photograph (left) compared to the digital display image of the same emulsion layer (right). Note that the image on the right represents data digitized from the photo shown on the left. The quality of the digitized data is of such high quality that one might not even recognize it as digitized imagery.

In order for the digitized multiband and multiemulsion photography to be analyzed by multispectral pattern recognition techniques, the three band digital data must be available in precise spatial registration. The details of the registration procedure have been previously reported(13). The registration process removes any translational, rotational and scale differences between the multiband images and creates a modified computer tape with the data stored in coincidence. This registration process is necessary for the multiband case; however, since multiemulsion film records the three emulsion layers simultaneously and in perfect registration, this problem does not exist for multiemulsion photography.

A major assumption made in quantitative analysis of aerial photography is that illumination is uniform across the entire frame of the photo (e.g. no vignetting, hot spots, or other lens distortions causing uneven illumination on the film plane). In many cases, this assumption is not valid. Vignetting is a frequent problem, particularly with color infrared or B&W infrared film. This can result in two agronomically identical fields of corn, for example, having very different tonal values (or colors) if one is located near the center of the photo and the other near the edge. However, when the data is in a digital format, mathmatical data handling functions can be applied to correct for some illumination variations.

The vignetting problem was apparent in the photographs being analyzed. The centers were significantly brighter than the edges, and the corners of the images were very dark. A computer program for correcting this type of error was employed to improve the quality of this data. Since only the lower right portion of the color IR photo had been selected for analysis, only this quadrant was processed to reduce the vignetting. Figure 6 shows digital display photographs before and after the correction for vignetting had been applied. Note the more uniform brightness from the center to the edge and the improved contrast near the lower right corner where the effect was most severe. This is only one example of the many correction and calibration processes which can be applied using digital techniques.

DATA ANALYSIS TECHNIQUES AND RESULTS

The analysis procedures used are generally referred to as pattern recognition techniques. The patterns involved in this research are spectral, rather than spatial, and consist of the measurement of density in each of the wavelength bands of photography. For example, an area in a corn field might have a medium, a high, and a low density value for the three emulsion layers on color infrared film. These three density measurements together comprise a vector describing the relative spectral response pattern for that small area of corn. The values are relative since each photo is exposed and developed to obtain a complete range of contrast in tone. Thus, each multiemulsion photo or multiband set of photos essentially consists of a large array of spectral pattern vectors which can be quantitatively analyzed by digital computer.

Many pattern recognition algorithms are available for use, and so one of the problems encountered is to select a reasonable algorithm for the particular objectives involved. One analysis technique used involves a maximum likelihood ratio, based on the Gaussian assumption. This algorithm was used first by LARS in research involving multispectral scanner data and has proved useful in establishing the feasibility of applying such automatic data analysis techniques to that type of remotely sensed data. The details of this algorithm and of the data analysis procedure have been described previously (6), so they will not be included here. However, a very brief description of how these techniques are applied to the data is necessary.

After displaying the photos on the LARS digital display unit, the analyst must locate several areas where the identification and perhaps condition of the ground cover is known. These "training sample areas" are designated to the computer when the analyst points the light pen at four spots encompassing the area of interest. A rectangle or square containing this area is then drawn by the computer on the screen of the digital display unit. Figure 7 shows an example of the digital display screen with some training areas designated. Next, the computer is statistically "trained" to recognize the spectral patterns of density values for each cover type or condition of interest in the photo. The pattern recognition algorithm is then applied, and each set of vectors in the entire photography is automatically classified into one of the cover types or conditions for which the computer was trained. The results of this classification can be displayed in both an image form and in a tabular format. These tables can show such things as a calculation of acreages according to the automatic classification of the various cover types, or the accuracy of the computer classifications for randomly selected test areas. The use of test areas enables the analyst to evaluate the accuracy of this automated classification which involves extrapolation from a relatively small portion of the area (the training samples) to the entire photo.

"Clustering" is another, more automated, technique (11) that can also be applied to digitized remote sensing data (i.e. multiband or multiemulsion photography, scanner data, or other types of multivariate data). In essence, in this technique an entire area is designated to the computer. Each of the spectral vectors contained in this set of data is automatically examined and the entire set of data is statistically divided into a number of groups or clusters, each containing data points having similar spectral vectors. The number of spectral groups is designated by the analyst, or if he specifies a larger number of spectral clusters than is actually present, the computer is programmed to reduce this number sequentially until the maximum number actually present in the data has been found. After the number and statistical parameters of the spectral clusters have been determined, each point in the data is automatically classified into one of those spectral cluster groups and the results displayed. At this point, the analyst examines the results and, based upon previously obtained information concerning cover types or conditions in at least a small number of areas, determines what each of the spectral clusters actually represents on the ground. For example, he may find that spectral cluster 1 represents soybeans; clusters 2 and 3 are both corn; 4 is roads; 5, 6, and 7 are trees; 8, 9, 10, 11, and 12 represent various soil situations; cluster 13 represents both pasture and hay fields, etc.

An example of the results obtained with this technique for a very small area on the photos is shown in Figure 8. The area was purposely kept small so that the classifications of the individual digitized points could be seen in the illustration. In this case, seven clusters were designated and the results indicate that three clusters were designated as different spectral categories of pasture (shown on the computer printout as., -, and = and also indicated by a large P, which was added by hand for illustrative purposes); one cluster corresponded to soybeans (I); two corn clusters were designated (O and M); and one cluster was designated for an area believed to be in diverted acres (/). The area indicated in the last cluster did not have positive identification because of a lack of ground observations on that particular field. This points out one of the difficulties in interpreting results obtained with this technique; namely, when spectral clusters are designated for areas for which ground observations are not available, the analyst is sometimes not sure how to interpret that spectral cluster. However, if the analysis takes place soon after the data are collected, ground observations can often still be obtained.

The major advantage of clustering is that the analyst is not responsible for designating the spectral categories present in the data. Too often we know too little about the spectral characteristics of the materials of interest and so have a tendency to designate cover type groups which we hope to be able to differentiate, but which may or may not be spectrally different.

The major disadvantage of the clustering technique is the enormous amount of data and therefore computer core and computation time that can be involved. The example in Figure 8 involved only 2500 data vectors, whereas the entire frame of 70 mm photography shown in Figure 1 produced over 4,000,000 data vectors, each consisting of three data measurements. Another difficulty encountered in using this technique is determining how many spectral clusters present in the data are significant. For example, for the clustering results shown in Figure 8, six clusters were not enough because the soybeans and diverted acres were assigned to the same cluster, but more than seven clusters simply divided the various species groupings into finer and finer subgroups. With twelve clusters designated for that small area, there were four clusters representing pasture, four representing corn, etc. How many clusters do you need before the spectral differences become insignificant? In this example, there may be many more than twelve spectral clusters present, but we believe that even using twelve was producing results showing some spectral groupings which were insignificantly different.

A classification was made using the maximum likelihood ratio algorithm to compare results obtained from the multiband and the multiemulsion data. Four cover types were chosen (corn, soybeans, pasture, and trees) and a set of fields containing these types was selected using the digital display. Both the multiband and multiemulsion photographic data were then classified using the same procedures. Comparison of the classification results is presented in Table 1. The fields and classes were the same in both cases, but the number of points in each field was slightly different due to human variability in picking field boundaries from two separate displays and due to different digitization rates on the different film sizes. The classification results show that the two film sensor types give approximately the same accuracy, with the multiband photography having only a slight accuracy advantage over the multiemulsion color IR. This result is interesting since it is known that the three bands in the color IR film overlap to a greater degree than the three bands from the separate film filter exposures. This increased overlap increases the correlation between bands and reduces the separability of different spectral classes in the scene. However, the closeness of the results both in this experiment and in a similar analysis of Apollo 9 photography of the Imperial Valley, California (2) tend to indicate that the color infrared film is an effective three-band multispectral sensor and offers the efficiency of requiring only a single film frame rather than three, as in the case of the black & white multiband photography.

DISCUSSION

Multispectral photography offers a means of rapidly and efficiently sensing the energy reflected from a scene. After exposure of the film emulsion, subsequent development of the film results in a specific density for each point in the observed scene. Several problem areas arise when one attempts to transform a photographic transparency into a numerical representation of scene reflectance. These problems include the accurate measurement of the film density at an adequate spatial sampling rate, film calibration, and data handling. Film calibration is required so that each numerical sample has some consistent physical meaning from one photo to another, while data handling problems include spatial registration of multiband data (if the data is not already in registration), spatial rectification, creation of a digitized image to allow human interaction, as well as data formatting, and storage and retrieval.

Density measurement of a single point can be easily achieved through use of a variety of devices. Rapidly obtaining a large number of closely and accurately spaced density samples over a two dimensional space is a more difficult problem, but many accurate scanning microdensitometers are available which can do this job. The most difficult part of the densitometry problem

TABLE 1. COMPARISON OF TRAINING FIELD COMPUTER CLASSIFICATION ACCURACIES FOR DIGITIZED MULTIBAND AND MULTIEMULSION PHOTOGRAPHY.

Class	70 mm Multiband B&W Photography		9" x 9" Color Infrared Photography	
	Points In Class	Classification Accuracy	Points In Class	Classification Accuracy
Corn	4645	94.5%	4041	97.8%
Soybeans	1615	98.1%	1748	85.1%
Pasture	153	100%	182	98.9%
Trees	273	91.0%	238	92.4%
Overall Correct Classification		95.5%		93.9%

appears to be the accurate and reliable measurement of the density of the different dye layers in multiemulsion transparencies. Color separation negatives were used in the analysis described in this paper. However, since use of separation negatives introduces another photographic process which can result in alteration of the photometric properties of the original photograph, direct methods would appear to be inherently more accurate for quantitative spectral analysis of multiemulsion photography. These direct methods incorporate the color separation process as part of the densitometry procedure through the use of color separation filters. One procedure employs multiple optical heads which allows color separation of a spot on a transparency through parallel use of several filters. Another approach achieves the same process serially, by scanning through one filter then rescanning through the next, etc. No matter which method is used, the same basic problems of effectively separating the three bands of information in multiemulsion film must be faced.

These emulsion separation problems are not encountered with separate black and white multiband photographs; however, the multi-image registration problem then arises if separately sensed and digitized photographs are to be analyzed. Because separate optical systems are used to obtain the individual multiband photos, differences in their geometric and photometric characteristics further complicate the registration problem. Thus, both multiband and multiemulsion data collection methods have their advantages and disadvantages. It is the purpose of this discussion to point out the possible trade-offs rather than to draw conclusions as to which method is best.

The problem of attaching consistent physical meaning to the density measurements has not, to our knowledge, been satisfactorily solved. There are three main problem areas here: (1) The density of the film across the frame is often not the same for a constant scene reflectance. Vignetting is one of the most common causes of this variation and can be corrected either empirically or functionally. (2) The relationship between density and exposure is difficult to determine. (3) The absolute value of scene reflectance represented by a given density must be determined. The density exposure relationship can be determined by using precision step-density wedges which produce known variations in density. This third problem area is the most difficult since it requires calibration panels in the scene or some precision light sensor to measure incident and reflected light. More research into these calibration problems is needed.

The major problem areas within the digital data handling and analysis realm are reflectance calibration, image registration, and pattern recognition algorithm development. Data storage and retrieval, image display, and graphic data display methods should be the subject of continuing research in order to develop all the software and hardware items that are required to provide a flexible and powerful analysis tool.

The analysis techniques described in this paper were developed at LARS/Purdue for use with multispectral scanner rather than photographic data. Because scanner data is originally recorded as an electronic signal, it can be quantified more easily and precisely than film. However, scanner data does not have some of the advantages of spatial resolution and geometry found in photographs. Therefore, the results presented in this paper are intended to illustrate that such analysis techniques can be applied to photographic as well as scanner data, once the photos have been converted to a digital format. We believe that for some applications, remote sensing involving photographic data collection is more appropriate than scanner data, and vice versa. Also, for some applications, automatic analysis techniques may be of great value in assisting the photo interpreter. We should not make the mistake in remote sensing of saying that the data collection should involve only photographs or scanner data or radar data or that the analysis techniques should be either manual or automated. Rather, we should use a combination of data gathering techniques and analysis methods that will allow optimum use to be made of the advantages of each, in accordance with the particular application.

Purposeful study of the huge quantities of remote sensor data which will be generated in the near future will require large and sophisticated computers and software systems. It is hoped that the discussion presented here will be of value to others planning the development of remote sensor data analysis facilities.

CONCLUSIONS

- Quantitative analysis of tonal variations is more difficult to achieve with multiemulsion than multiband photography, because of difficulties in reliably separating and measuring the tonal values contained in each of the emulsion layers of multiemulsion photography.

- Automatic analysis of data obtained with a scanning microdensitometer is sometimes more difficult with multiband than multiemulsion photographs, because of the problems of spatial registration of the separate sets of data.

- The need to convert aerial photographs to quantitative density measurements through use of microdensitometer techniques, and to apply automated data analysis techniques to this data, is greater on small-scale than on large-scale photography. This is because the interpretation of small scale photos (i.e. 1:50,000 to 1:250,000) is more dependent on tone. This need is also greater for multiband than for multiemulsion photos because of the difficulty in manually handling several different photos of the same area, and of visually detecting and properly interpreting subtle tonal differences.

- The greater the number of multiband photos being utilized, the greater is the necessity of quantitatively analyzing variations in tonal response on the photos.

- Computerized correction procedures can be applied to digitized photographs to adjust for uneven illumination across the photo (such as that caused by vignetting).

- The capability for precision in quantitative analysis of digitized photography appears to be greater than the quality of photographs from which the data is obtained, due to difficulties in calibrating the film to account for variations in exposure and development and to difficulties frequently encountered in controlling illumination across the entire frame.

- Automated analysis of relative tonal patterns in different wavelength bands of small-scale photographic imagery is feasible, at least in certain situations, for identifying various cover types and conditions.

- Automated data handling techniques must have close human supervision and control, and the results of such quantitative techniques should be carefully interpreted to insure that errors have not occurred in the analysis sequence. These automated data handling and analysis techniques offer a powerful and useful tool, but only as a supplement to manual photo interpretation methods.

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1-a. Color Infrared Photo, .51-.89 μm.

1-b. B&W Panchromatic Photo, .51-.61 μm.

1-c. B&W Panchromatic Photo, .59-.71 μm.

1-d. B&W Infrared Photo, .68-.89 μm.

Figure 1. Comparison of Multiemulsion and Multiband Photos. The multiemulsion, color infrared photo (Figure 1-a) consists of three emulsion layers combined into a single color photo, whereas the multiband photos (Figures 1-b, 1-c, and 1-d) are individual black and white photos, each representing a different film-filter combination and each obtained with different cameras. In this case, the three multiband photos represent approximately the same wavelengths as the three emulsion layers of the color infrared photo.

1408-04.1/4

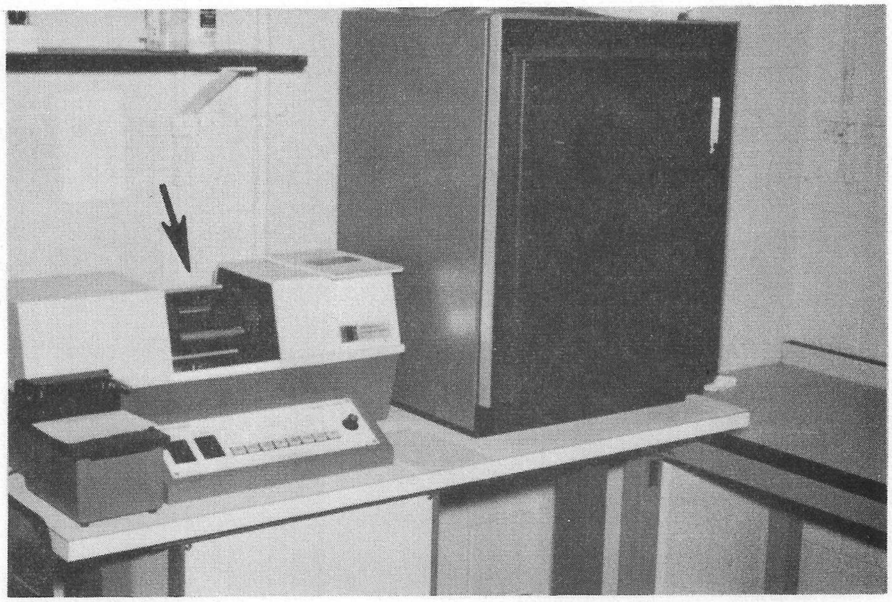


Figure 2. Rotating Drum Microdensitometer, Used to Scan and Digitize the Photos. The photo transparency is mounted on the drum designated by the arrow, and the digitized data is recorded on the tape recorder on the right.

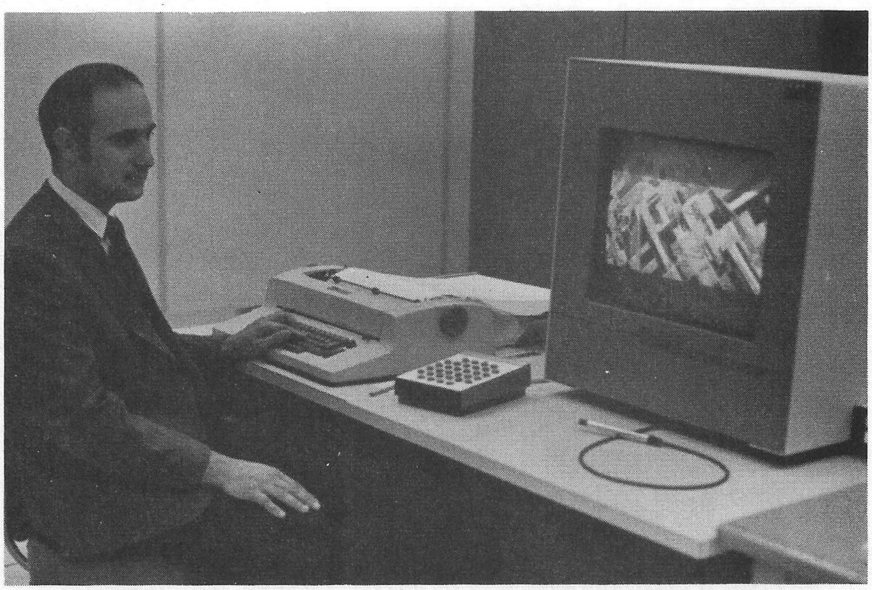
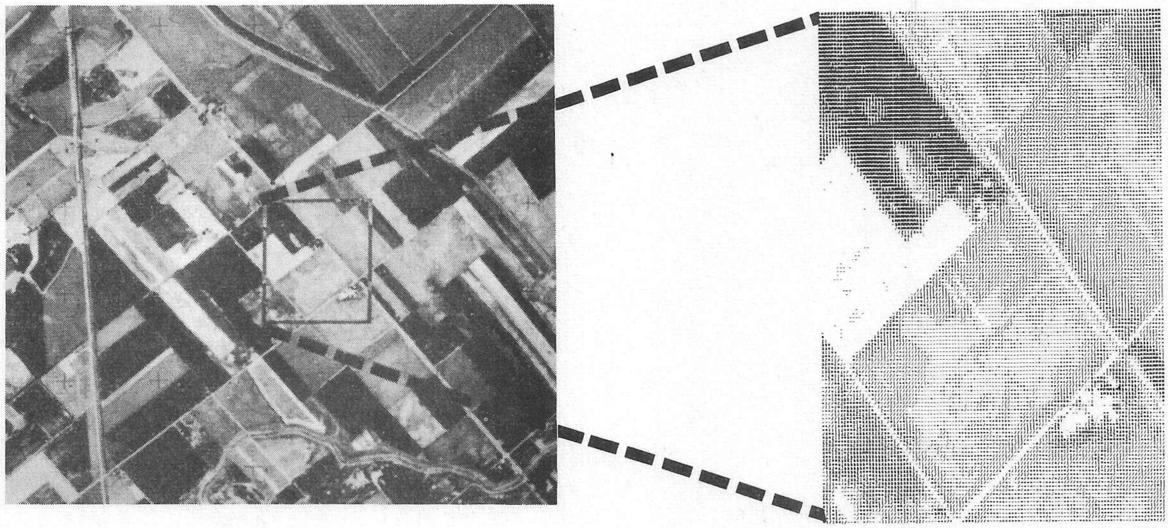


Figure 3. LARS Digital Display Unit, Used to Display Digitized Photos (or Scanner Data). By using a light pen, training and test areas can be selected for further analysis (see Figure 7).



1408-04.5/38

Figure 4. Two Methods of Displaying Digitized Photography. Left--Digital display image of test area, using display unit shown in Figure 3 and representing variations in tone with 16 levels of grey. Right--Computer line printer display of a small portion of the area shown on the left. Different density levels are represented by different computer symbols which emphasize the individually digitized points in the data. The .59-.71 μm multiband photo is shown.

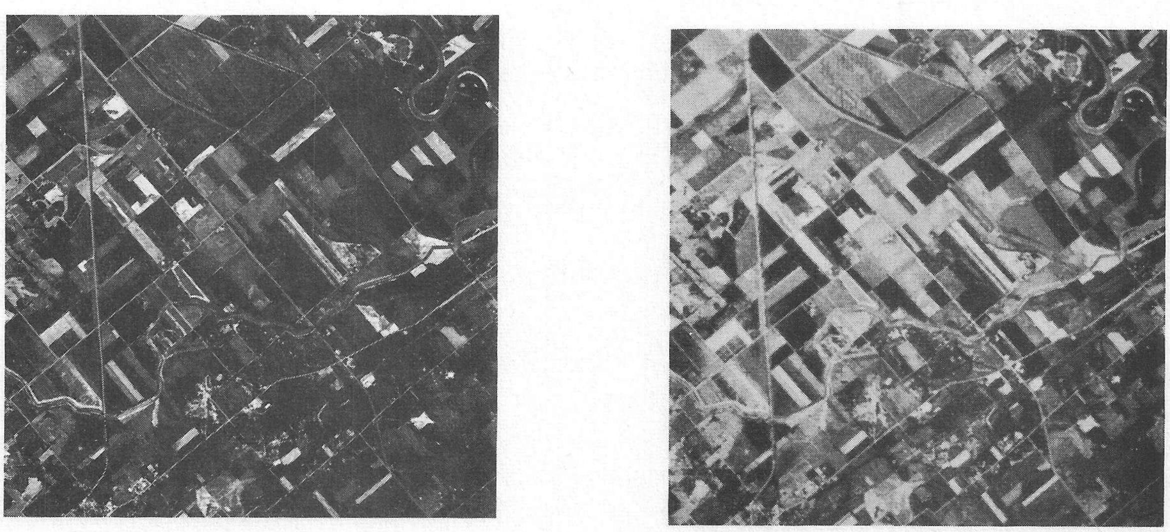


Figure 5. Comparison of One Layer of Multiemulsion Photo (left) and Its Digitized Image (right) for the Test Area. This area encompasses the lower right quadrant of the photo shown in Figure 1-a. Only every other line and every other point digitized were actually displayed in the image on the right. The .59-.71 μm wavelength separation is shown.

1408-04.7/5

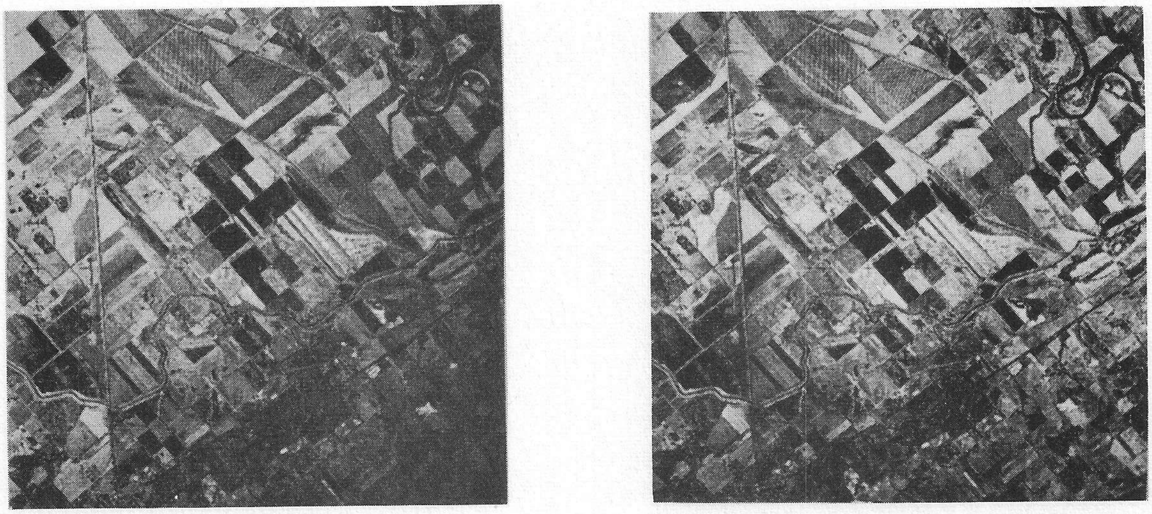


Figure 6. Comparison Showing Digital Correction for Vignetting. Left--Original digital display image in the .68-.89 μm wavelength band showing uncorrected data. Right--Digital display of same data, with a factor applied to correct for vignetting. Only the lower right quadrant of the original photo (Figure 1-d) is shown.

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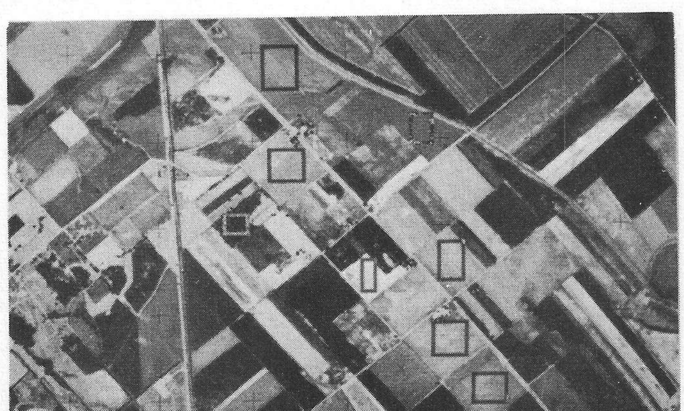

Figure 7. Training and Areas Designated Through Use of Digital Display and Its Light Pen.

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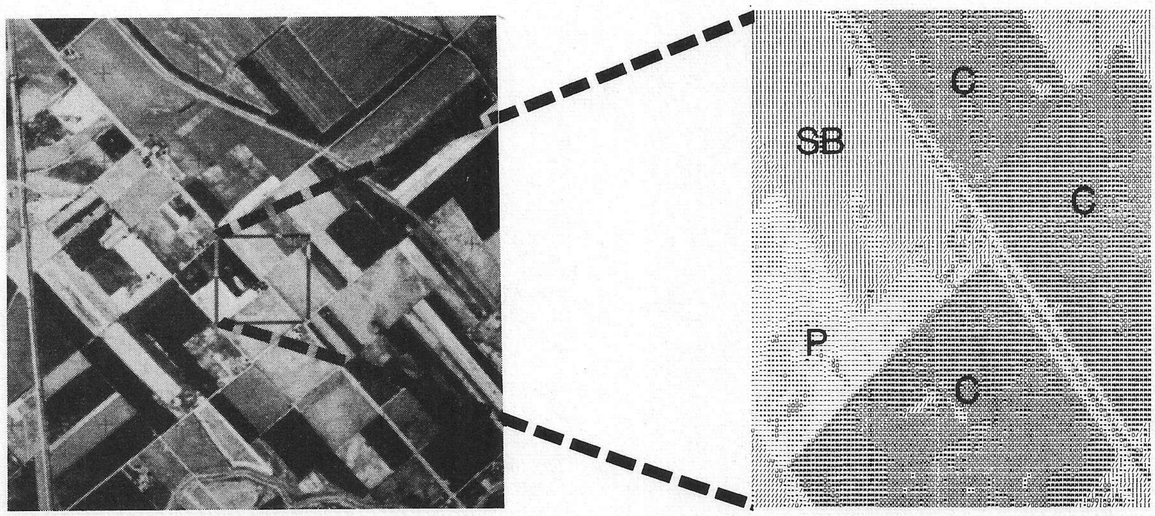

Figure 8. Automatic Classification Results, Using Clustering Technique. Left--Digital display image (.59-.71 μm). Right--Computer printout of crop species classification, using all three bands of digitized multiband imagery.

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