To the Graduate Council:

I am submitting herewith a thesis written by James Jonathan Jefferies entitled "Delineation of Urban Areas Using Remote Sensor Multispectral Data." I recommend that it be accepted in partial fulfillment of the requirements for Master of Science in Planning.

Joseph Prochaska, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

DELINEATION OF URBAN AREAS USING REMOTE SENSOR MULTISPECTRAL DATA

A Thesis

Presented for the

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Degree

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James Jonathan Jefferies

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DEDICATION

The author wishes to dedicate this thesis to his loving daughter, Jessica Elizabeth and his parents, Mr. and Mrs. James R. Jefferies.

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ABSTRACT

Remote sensing--the noncontact recording of the earth's surface from aircraft and satellite--is increasingly looked to as a source of information for planning at regional and national levels. To successfully utilize the flood of information expected from such sources, it will be necessary to apply machine processing to the information extraction. This thesis satistically compares spectral information from selected urban and non-urban land uses to show that those areas could be differentiated in such processes.

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GLOSSARY OF TERMS

Feature - some quality or attribute by which an object or class of objects may be differentiated or identified.

Imagery - a physical recording of spatial phenomena usually as a picture.

Multi-spectral - involving differences in response to different portions of the electromagnetic spectrum.

Pixel - if an image is defined as a grid or matrix of light and dark tones, each cell or element within that image is a pixel (picture element).

Radiometric - relating to radiation measured in terms of intensity and wavelength.

Remote sensor - a device for noncontact recording of the physical world, for instance a camera.

Spectral - of, or pertaining to, some portion of the electromagnetic spectrum as defined in terms of wavelengths.

Spectral window - a defined portion of the electro-magnetic spectrum which is used for a specific purpose; often of importance because of lack of radiation attentuation by gases, aerosols, or particles.

CHAPTER I

INTRODUCTION

I.1 RESEARCH HYPOTHESIS

There exists sufficient spectral information of a quantifiable nature in remote sensor imagery to broadly differentiate land use in urban areas.

I.2 PLANNING PROBLEM

Land, one of our basic commodities, is finite in its availability. The monitoring of land use--while always of interest--has developed into a crucial planning function at all governmental levels, due to the permanency of conversion, the accelerating amount of change and an increasing concern with quality of life (14). While land use has been a long standing concern of local governments, it is increasingly becoming of interest to regional, state, and national bodies. The transition from local to regional, to national and eventually to international concerns argues for unified, timely and objective information sources. That such information does not exist under present conventional systems was clearly demonstrated in the mid 1960's experience of the Northeast Corridor Transportation Project (NECTP). That effort relied almost entirely upon existing records of county planning agencies to synthesize a land use data bank for support of regional forecasting models. The following difficulties were encountered:

1. Of 166 counties in the study, 125 provided complete data and 21 provided none.

2. The data collected represented the period 1957-1966 rather than the desired study year 1960.

3. Twelve counties were able to provide data for only a portion of their total areas and it was necessary to expand the existing data to represent the entire area.

4. Neither state highway agencies nor regional transportation and planning agencies could provide the desired information.

5. Some counties were able to provide data for as many as twenty land use categories while others had only four available and so governed the level of classification (14).

While the NECTP was not a complete information data bank system, that experience does illustrate some of the problems which face any agency attempting to aggregate information from existing administrative units.

Remote sensing--recording the physical environment by photographic and non-photographic sensors from aerial platforms--has been recognized to an increasing degree as a source of information for planning. There are three major advantages of remote sensing by comparison with more conventional information sources (2). These advantages are: speed and ease of gathering data, objectivity of the original data and an overview which ignores artificial boundaries. Remote sensor imagery can be regarded in an abstract sense as having thermatic, spatial, and temporal information which may be extracted for use in a particular problem. There is the added advantage that at

a later date additional or different information may be extracted. Thus the use of such an information source would seem of increasing desirability as the scope of the planning operation expands.

Though the advantages of remote sensing are now being recognized as an input to many planning problems, it has been only sporadically used in the past. The primary reasons for this seem to have been non-familiarity on the part of planners and absence of information systems designed for its use (2). In the past few years NASA and the Department of Interior have had the major responsibility for developing civilian applications of remote sensing for use in urban and regional planning (14). There are several prototype information systems presently being tried out which use remote sensor imagery--the Census Cities and the CARETS projects are examples. In addition, at least one state, Georgia, is actively using satellite imagery from ERTS A as an information source for a state-wide geological atlas for input to land use studies. While these systems have not been fully proven, they do serve to indicate a future trend.

Both of the above federal prototype projects appear to have similar themes though different applications. The Census Cities Project has a number of related purposes which are in part, directed toward correcting the lack of urban information systems capable of using remote sensor imagery. These purposes are:

1. "To assess the role of remote sensors on high altitude platforms for the comparative study of urban areas;

2. To detect changes in selected U.S. urban areas between the

1970 census and the time of launching of an Earth orbiting sensor platform prior to the next census;

3. To test the utility of the satellite platform to monitor urban change as the 1970 census returns become available from small areas, and serve as a control for sensor image interpretation;

4. To design an information system for incorporating graphic sensor data with census-type data gathered by traditional techniques;

5. To identify and design user oriented end products or information services;

6. To ascertain what organizational capability would be needed to provide such services on a continuing basis" (57).

The Central Atlantic Regional Ecological Test Site (CARETS) is a "prototype or demonstration project for a proposed operational land use information service in the Department of the Interior" (3). Part of its underlying rationale is to test the feasibility of using ERTS satellite imagery for an experimental, regional, environmental information system.

In such applications there appear to be several common conceptions. One of these conceptions is that with enlargement in planning scope, it seems desirable to change the type, detail and area of coverage. That is, low-altitude large-scale imagery would be more desirable for a local problem, while for regional, state and national uses, smaller scale, high altitude or satellite imagery would be more desirable. Change in scale is closely associated with change in resolution or detail of information and with the amounts of information

which result. In a physical sense, the small scale imagery of a high altitude aircraft or satellite sacrifices spatial resolution to achieve a view of larger areas. The loss of detailed information is in part compensated for by the revelation of spatial relationships and patterns. While there are choices and tradeoffs to be made as to the type of remote sensor systems used as information sources, the advantages of the large coverage of satellite imagery would make it attractive to regional and higher planning bodies. Moreover, the availability of such imagery at the present reasonable prices would likely make it of interest to more local agencies. Though it is only a prototype system, ERTS A does serve to indicate the increase in information flows which can be expected as remote sensor technologies develop.

Since July 1972, The Earth Resources Technology Satellite (ERTS A) has been collecting and transmitting multispectral data of earth. The satellite is in a sun synchronous orbit which passes over every point on the globe once every eighteen days. The Multi Spectral Scanner (MSS) is only one of two major remote sensing devices on board ERTS A. The other, a Return Beam Vidicon (RBV), was discontinued because of insufficient power. The MSS records the earth's reflected light in four wavelength bands--blue, 0.5-0.6μ; green, 0.6-0.7μ; red, 0.7-0.8μ and near infrared, 0.9-1.1μ. This information is in turn transmitted down to earth receiving stations where it is handled in digital form on magnetic tape or reconstituted to a pictoral image. Because of systems limitations, the MSS is restricted to a relatively large resolution element. When considered in imagery format, either as a digital

printout or as a photographic image, a resolution element is often referred to as a pixel (picture element). One MSS pixel represents--dependent upon satellite altitude and viewing geometry--a minimum of 1.1 acre on the earth's surface. This may be translated as some 600 ERTS pixels per square mile or approximately 18 pixels in a 20 acre site. On the 9-in. by 9-in. ERTS photographic imagery (covering approximately 13,225 sq. miles) there are some 8,640,000 pixels per band or 34,560,000 pixels for all four bands that constitute one complete ERTS image. After less than two years of operation there is a potential of over 10,000 ERTS A images of the continental United States alone and this represents only half of the imagery originally expected. The flow of imagery has so increased that it is anticipated that future satellites will produce more imagery in one hour than can be interpreted in one year using conventional methods of photo interpretation (2). Increasingly, the use of automatic or machine interpretation of imagery is being recognized as necessary for successful utilization of this wealth of information.

The automatic interpretation of remote sensor imagery employs a set of techniques broadly called pattern recognition. By comparison with more conventional photographic interpretation (PI), Pattern Recognition (PR) is relatively less sophisticated but requires less human attention. It is recognized that an all-inclusive, automated image interpretation will not be possible in the near future. There is, however, sufficient justification for the development of automatic procedures in that:

1. "Machines can duplicate simple human functions and, by doing so, achieve higher speeds, a higher degree of objectivity and, possibly, higher accuracy.

2. The machine implementation of simple jobs frees human interpreters from routine work and makes them available for more demanding tasks.

3. A machine can handle more dimensions of information than a human. As an example, multiple imagery of the same area. This opens up new areas for the processing of remote sensing information which lie beyond human capabilities" (49).

Small scale imagery such as ERTS would seem most applicable to planning on a regional basis. A regional planning body would have a number of interests, including information on urban areas. In application to urban areas there are three general uses of remote sensor imagery. Robert Alexander has defined these as:

1. Delimitation of Urbanism: the ability to delimit the extent of urban areas, separating urban from non-urban and establishing their relation to one another is important from the theoretical and practical standpoints.

2. Determination of Urban Land Uses and Structures: this has been the conventional and best documented use of remote sensing to date.

3. The study of urban dynamics: an area which includes expansion of the city's boundaries and changes within the internal structure (2).

The first two of these purposes are in part the subject of this

thesis. The third is the result of interpretation of the first two over time.

I.3 STATEMENT REGARDING THESIS

There are several factors which have strongly affected the execution of this research and the possible uses which it can achieve. The author feels that these should be explicitly stated as a part of the rationale for the research subject and the choice of test site.

The subject matter of this thesis (by some estimates) falls outside the normal domain considered particular to planning. Moreover, the subject matter crosses several disciplines which, to varying degrees, are working in the area. However, as developed in the introduction, Remote Sensing and information extraction by pattern recognition are being developed as a new information input to planning. The CARETS project has designated the use of interactive systems using digitized imagery and the use of pattern recognition techniques as one of their interests (3). That planning is an interdisciplinary field which serves as a locus for the application of many disciplines, would argue for its practitioners being involved in the development of new techniques for its use. For the author, this study has involved a learning experience in heretofore unapproached fields. For other readers, it may serve as an introduction to the more sophisticated and complex approach to this type of information source, as well as give some proof to the feasibility of the research objectives.

I.4 STUDY AREA

The choice of the Knoxville area as a test site was partly because of its proximity and the availability of data and necessary facilities. As a test site, its physical characteristics are similar to most North American cities. The climate is temperate with the surrounding non-urban areas being primarily farm with some forest composed of deciduous and coniferous trees. In terms of spatial arrangement, it generally follows the pattern common to North American cities, particularly those in the east. The central business district is successively ringed with areas of support and residential uses with the outermost fringe being the most recently developed residential areas.

CHAPTER II

PATTERN RECOGNITION IN REMOTE SENSING

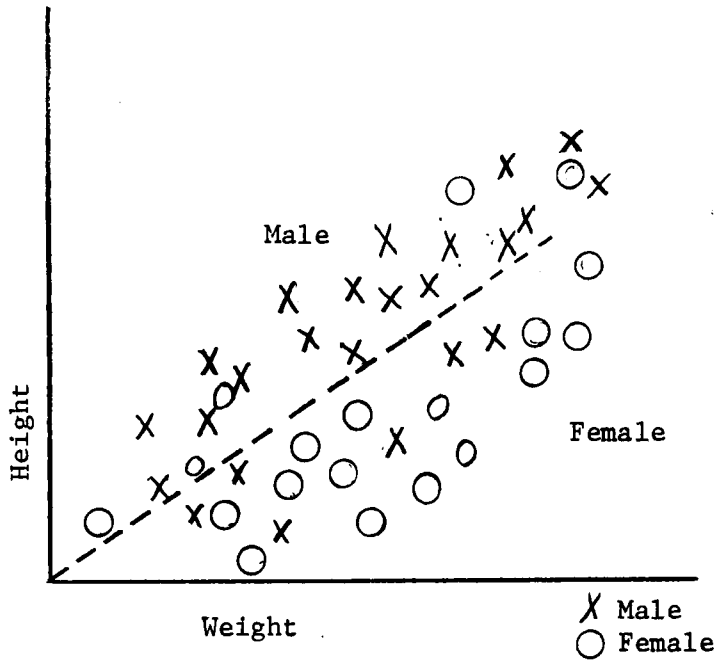
II.1 PRINCIPLES OF PATTERN RECOGNITION

Pattern recognition concerns the classification of information by recognition of common measurable attributes. In remote sensing the information of interest is the pictoral recording of the earth's surface. The subject of this thesis is whether or not there exists sufficient information of a quantifiable, measurable nature in remote sensor imagery as to permit differentiation of urban areas. The actual mechanics of pattern recognition are touched upon only so that the research rationale might be better understood.

There are several important basics to pattern recognition. Two of these are feature measurement techniques and the concept of feature space. The word "feature" is used here to mean a measurable attribute--that is one that can rationally be transformed into a mathematical or other symbolic form. Different features are preferably orthogonal to one another, i.e., not inter-correlated with one another. The selection of features is--at this time--more of an art than a science. The choice of what constitutes a desirable feature is most often determined by the technology in the particular field of application and the intuitive grasp of the researcher. Feature space is the concept that each different type of feature constitutes a new dimension by which classes may be differentiated. If an object or thing to be classified is

measurable using N features, then that object can be defined as a point or vector in an N dimensional space. For example, humans might be measured using two features, such as weight and height. Then each person measured may be regarded as an input within some pattern which has two measured features. Diagrammatically this might be represented as a two dimensional "feature" space with weight and height being respectively the horizontal and vertical axis (Figure 1). Each person or pattern then would be represented as a point or vector within that feature space. If it can be said that there exists some relationship between the features, weight and height and some class structure, then it is possible to partition the feature space into mutually exclusive classes. An example of such a class structure might be the recognition of sexes by weight and height differences. The partitioning boundaries are called decision boundaries, surfaces, or hyper-planes.

As a system, pattern recognition has two basic components: a feature extractor or receptor and a categorizer or classifier (54). The feature extractor has the function of measuring the feature including its location in the case of remote sensor imagery. Another definition of feature extraction is that it serves in transforming the feature from an information dimension to a feature space. The classifier then has two functions: to detect and identify the common pattern of inputs for different classes (learning) and to recognize this pattern in any new input so as to classify it as one of several classes already defined (evaluation). This latter function may be accomplished on the basis of already known features of the defined classes (45) or it may be learned



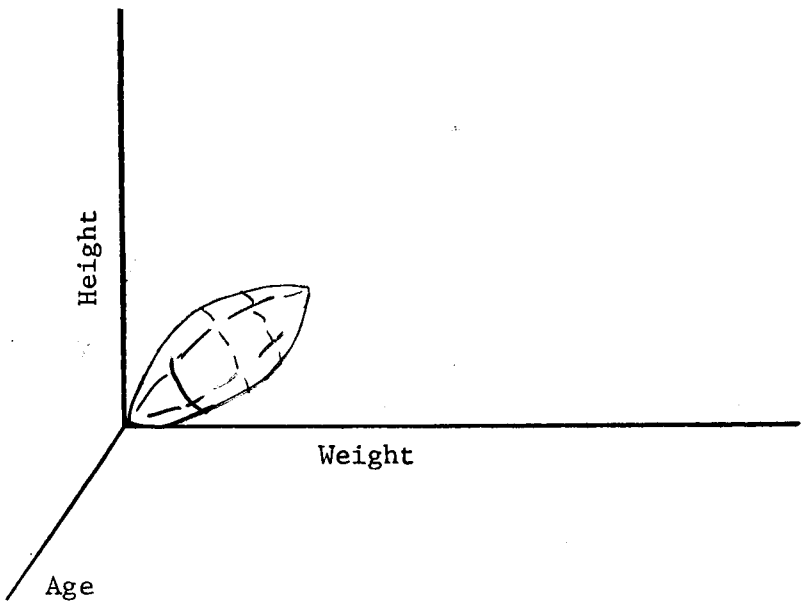


Figure 1. Representation of feature space in two and three dimensions.

on the basis of information being presented by clustering. The most complex part of almost all pattern recognition systems is the classifier. Whereas one would hope that the classes would be clearly separable and identifiable, this is rarely the case. Thus the partitioning of the feature space becomes a complex problem. In the preceding example of weight and height there is an obvious correlation between the two features. In such a case it would be highly possible that some classes would be inseparable on the basis of such features. From the example of weight and height it is possible that a boy might have the same height and weight characteristics as a mature woman. When possible, the selected features should be orthogonal to one another, i.e., not correlated. But it may be that the choice of features is limited by external conditions. In such instances, inclusion of additional features may permit separation of the desired class structure. In the example of weight and height, inclusion of age as a dimension might allow a better differentiation of sex. Other techniques which might be applicable are principal component analysis or varimax rotational transformations of the original data. The classification criterion is either directly or indirectly the minimization of misclassifications (54).

There are three operational modes which are used in pattern recognition of pictorial information and of spatial information in general. The first and most often used is the point operation mode. In a point operation, individual pixels or a very small group of pixels are measured in terms of N features. These measurements then form the N dimensional vector for input to the classifier. This has

been the most frequently used mode because of its facility of application to spectral information from scanners or photographic images. The second mode is termed a local operation. In this mode an entire scene is involved and relationships of pixel to pixel are considered. This mode is necessary for the use of the spatial dimension of information. Though not as extensively implemented as the point operation, there is considerable work being performed in this area, particularly with relationship to Fourier analysis and related techniques. A third mode, which is largest in scale, is the global operation. In a global operation the entire image is dealt with in a single operation, as a pattern made up of patterns. This terminology is, at times, confusing because an image is broken into windows. A Fourier transform of a window is a global operation on that window. With relation to the entire image it is a local operation. For this reason it seems desirable to define carefully whether one is dealing with a window or an entire image.

The most recent and sophisticated advances in the field use the global mode and approach pattern recognition as a linguistic problem. Narsimhan in "Automatic Interpretation and Classification of Images" (20) has proposed a general framework for an "adaptive, interactive picture processor" using this approach. His work postulates a framework with four subsystems. The first of these would be a feature extractor. The second subsystem would work in the point or local mode. Its output would be a line diagram or sketch together with auxiliary information about the local features. A third unit would be a global aspect processor which would act on the information from all the local

operations. Information from this unit would be: connectivity, boundary shapes of delimited regions, relationships between these, information about "formgestalt," and scene layout. To tie the whole system together would be the fourth subsystem--an "adaptive language user" which would have embedded in itself a syntax-based descriptive schemata for pictures. This then is somewhat different from the approach portrayed previously. The actual mechanics would be to define what exists locally, either quantitatively or symbolically, and then the global operation would use a "linguistic" scheme which would operate to define relationships between the measured local features. It should be pointed out that spectral information from a local operation could be used in such a scheme as the input to the global aspect processor.

II.2 FEATURE EXTRACTION FROM REMOTE SENSOR IMAGERY AND RELATED PROBLEMS

In the application of pattern recognition to remote sensor imagery the basic information features or dimensions are: spectral--the reflectance or emittance of electromagnetic radiation by wavelength; spatial--texture or the change of reflected or emitted radiation across the imaged space; and temporal--changes in spectral or spatial information with time, usually seasonal. Though not common, the state of radiation polarization is another possible dimension (54). The feature extraction, sometimes referred to as quantification, may be accomplished directly with electro-optical scanning devices which would sequentially scan the area. A prime example of this system is the Earth Resources

Technology Satellite (ERTS). The feature extraction may also be accomplished by taking a photographic image and scanning it with an optical density measuring device such as a microdensitometer. In either case, the image is transformed into a digitized array in which each array element refers to a quantified radiation level. From either extraction system, the minimum resolvable element corresponding to one array element is termed a pixel, picture element. In mechanical scanning systems, the pixel's size can be equated to the Instantaneous Field of View, IFOV, which is a function of optics and detector size. In non-mechanical systems, the pixel's size--smallest resolvable area--is largely determined by the optical system and other system parameters. The question of whether or not a terrain feature, corresponding to one pixel's equivalent in ground area, can be resolved is dependent upon the magnitude of contrast between the target and its surroundings and to what extent it fills the resolution element or is situated in two or more pixels.

There are several problems intrinsically associated with feature extraction in remote sensing. These may be broadly grouped into (a) Geometric distortions and (b) radiometric distortions. One result of these distortions is a hindrance in the ability to transfer sample feature measurements from one piece of imagery to another. This necessitates the relearning of class features and the redefining of decision boundaries for each image. This is of particular importance to the use of spectral information.

These problems strongly influence the choice between a priori

and posterior determination of decision rules or boundaries. As the name suggests, the a priori approach uses preselected decision rules on which to base classification. The posterior approach, by comparison, pulls samples from known areas, termed training sets, to establish the decision boundaries. The posterior method would seem the more common approach in remote sensing since the distortions largely prevent use of the a priori approach. Though improved sensor and recording technology will alleviate these problems of distortion, environmental factors, such as atmospheric interference, associated with remote sensing would seem to dictate that each image be treated separately. This is inherent in the following discussion of these problems.

Geometric distortions do not directly affect pattern recognition in the point or local operation mode. They may, however, affect interpretation and intelligibility of the final results. In a global operation, they could conceivably affect the pattern recognition operation. Geometric distortions may be broken into three groups:

1. Sensor related errors: this includes distortions due to the optical system, the scanning system and recording system.

2. Sensor platform related problems: these are caused by the exterior orientation of the sensor: attitude, altitude and horizontal position.

3. Object (earth) related errors: earth rotation or movement, atmospheric refraction and terrain or point elevation (54).

Depending upon the system, corrections for geometric distortions could be carried out before or after pattern recognition or not at all. The important point is that distortions could be corrected.

Radiometric distortions, on the other hand, do affect pattern recognition in the point, local modes and the global mode. Thus far we have made the assumption that the signature or recorded radiation features of any target remain nearly the same over space. This is not necessarily so. Radiation (light, heat, etc.) whether reflected or emitted by the target of interest are in one sense electromagnetic waves. With a few minor exceptions such as lasers, most radiation is composed of different wavelengths which have some characteristic distribution. Reflected radiation has as its principle source the sun. Thus the amount of reflected radiation by wavelength (the spectral characteristic) is determined by the distribution of the sun's radiation by wavelength and the target's geometry, reflectance and absorption characteristics by wavelength. Emitted radiation is the phenomena of all matter above absolute zero giving off radiation. Its distribution by wavelength is primarily dependent upon temperature, and material qualities, such as emissivity--the ratio of emitted radiation to what would be expected of a perfect radiator at that temperature--and surface texture.

Radiometric distortions in the recorded target signature may be generalized in three groups:

1. differences in reflectance or emittance by the target,

2. atmospheric attenuation during transmission, and;

3. distortions and variations in the sensor's measuring device (54).

Changes in reflectance or emittance are often related to the viewing angle and, in the case of reflectance, with the sun's angle. Atmospheric attenuation is governed by the presence or absence of particles and aerosols along the transmission path. It is possible for localized bodies of such materials to exist, for example, around an industrial section. There are, however, spectral windows in which the attenuation is relatively insignificant. Through the visible spectrum the attenuation is relatively low with some scattering in the blue region and absorption in the longer infrared wavelengths. The sensor related radiometric distortions are dependent upon the system under consideration though they are often related to problems in optical components and the geometries involved in scanning.

The variability of target signatures in remote sensor imagery due to radiometric distortions may be dealt with in several ways (54). The first of these is image restoration processes which try to eliminate the radiometric distortion. Unfortunately, these require knowledge about the distorting factors. Often such information is available only with difficulty or not at all. Secondly, there is a simplified approach of normalizing preprocessing techniques which alleviate these radiometric distortions for one image and which is especially applicable to multispectral data. If an assumption is made "that the relative magnitude of spectral signals for a given terrain type remains constant under varying intensity of irradiance various types of ratios between spectral channels can be calculated:" (54)

1. Ratio between adjacent channels:

   R(i) = S(i)/S(j) where S(i) and S(j) = signals obtained in neighboring channels i and j;

2. Ratio of difference between adjacent channels to sum of same channels:

   R(i) = S(i) - S(j)/S(i) + S(j)

3. Ratio between individual channels and sum of all channels:

   R(i) = S(i)/SUM S(K's) K = 1 to n.

It should be noted that such preprocessing techniques incur a loss or compression of information. As an example, the first ratio reduces the number of dimensions from N to N - 1 and in all three cases information as to absolute intensity has been sacrificed. This set of techniques is most applicable to radiometric distortions of a global nature, i.e., that occur over a whole image but are limited to that image.

II.3 CLASSIFICATION TECHNIQUES APPLIED IN REMOTE SENSING

The image classifier segment of a pattern recognition system is logically a computer operation. As such, it has two parts: hardware--the physical machine-- and software--the techniques, logical processes and mathematical algorithms by which classification is carried out. The extremely large quantities of data and the desire for optimal processing times would argue for the use of analog computers. However, these devices are hardwired so that digital computers are almost exclusively

used because of their flexibility. As the state of the art in pattern recognition is evolving so rapidly at the present time, it would be difficult to predict what form an optimal hardware system would take or if a general system would be possible.

There have been numerous classification techniques proposed and tried in application to remote sensor imagery. Though there are different biases and terminology applied to different types of classification techniques, there are basic divisions. Dieter Steiner in Geographical Data Handling distinguishes between:

1. Discriminant analysis techniques and cluster analysis techniques. In the first case a training set or sample is used to establish the decision making rules necessary for the classifier. In the second case, no training set is available and subdivision of the feature space is made by attempting to locate natural groupings, clusters. The nature of the clusters are determined afterwards. In both cases, some measure of similarity is necessary and the most commonly used measure is Euclidian distance or standard distance to class centroids in a multi-variate normal distribution. Other possible measures of similarity might be based on correlation and related concepts.

2. A second division of classification techniques is between deterministic and statistical. This terminology may be confusing as probability concepts underlie almost all pattern recognition techniques. In some instances, however, measurements are made in a deterministic manner using functions and calculating dot products of the general type

W•X where W is a weight and X is a feature vector. Statistical techniques are those techniques which are directly based on probability distributions.

3. A further distinction may be drawn between parametric and non-parametric methods. In the parametric case the distribution is known or assumed. In the non-parametric case the distribution is unknown. The phrases non-parametric and distribution free are often used interchangeably though there is a slight difference in the meanings. In the non-parametric or distribution free case the attempt to discern the existance of natural as opposed to arbitrary groupings implies the operation of the central limit theorem and therefore the existance of a distribution. This would be the case even though the distribution is not known. For the purposes of this field of application, the preferable definition as used by many statisticians would be that "non-parametric" or "distribution free" means that no assumptions are made regarding the form of the distribution (54).

There is, then, an underlying basis in probability theory for most pattern recognition techniques. The common conceptual approach portrayed previously is that when viewed as a statistical problem, classes of patterns are mathematically treated as multivariate random processes. Each member of a class is an N dimensional vector where each dimension represents a measurable and preferably non-related quantity. Classification, then, can be broken into two problems: (a) learning the common properties of a set of N dimensional vectors which represent samples of a class, and (b) identifying any new vector

by measuring its similarities (most often in terms of distance) with the class samples. Sebeysten views both of these problems as being related to statistical hypothesis testing. "Learning is the estimation of the probability densities describing the distribution of the set of samples in the vector space, while recognition is based on evaluation of the already learned conditional probability density function on each class at the point in the vector" (feature) "space that represents the new input to be classified" (45).

To determine the accuracy of the learned decision rules, known samples are submitted for classification and a percent correct classification is calculated. In some studies, the training sets have been used to check the accuracy, but it would seem preferable to use additional new sites.

II.4 FINAL PRODUCT

After the imagery has been recorded, digitized (assigned a numerical value for each pixel) and subjected to pattern recognition, the final product must then be arranged in some useful form. Dependent upon the use intended, tables could be created listing classes and desired breakdown of information. A more useful product might be a map of classes which would retain a spatial view of the information. Such mapping could be a simple process of writing out on some device the original imagery matrix with class designations in place of the original light intensity measurements. There are numerous output devices including interactive CRTs (television type displays) which allow the

user to modify the classification process or designate areas for re-submittal. Often a most economic solution is the high speed printer available at most computer installations. One product then could be a computer printed digital thematic map of the imaged area showing spatial relationships of some subject of interest.

II.5 LIMITS OF THESIS

The research objective of this thesis is to determine the feasibility of differentiating between urban and non-urban land uses on the basis of quantifiable features as recorded by a remote sensor. There are several limitations inherent in this study. Because of the constraints of time, facilities and available personnel, this thesis is confined to the study of designated representative areas for which imagery existed and could be quantified.

Of the three basic information dimensions mentioned previously, this thesis deals primarily with spectral information. The comparison of spectral response divided into bands is termed multispectral and corresponds to a point operation as mentioned earlier. As of the writing of this thesis, it is presumed and mathematically argued by many that local and global operations, principally in the spatial dimension, provide a greater amount of usable information than point, i.e., spectral information. The first two chapters of Automatic Interpretation and Classification of Images deal in part with this question. Though considerable theoretical work has been accomplished in this area, such as the paper by Narshimhan, and including some work

in implementation of operations such as analysis using Fourier transforms as a part of the feature extraction operation, there are at this time limitations in terms of computer hardware and software which have precluded a complete system being implemented. Multi-spectral pattern recognition, on the other hand, has been tried out to some greater extent. That its use is documented and to some extent that it is more easily implemented are a part of the rationale for the technical approach of this thesis. Moreover in the context of a complete system, which is still being developed, the use of spectral data in a point operations mode might be used to complement the global operational mode on spatial data.

A second problem lies in the applicability of information derived from this source. Because of our inability at the present time to sufficiently stabilize and standardize the physical recording of remote sensor imagery and because of environmental factors affecting such recording, it is necessary to provide classifying samples for each image. With the advent of satellite imagery, however, imagery interpretation will probably take on global aspects. This calls for relatively stable features with some degree of transferability. This is expected to be a problem in the application of spectral data.

Another potential difficulty if such systems are put into world-wide operation lies in that several cultural areas may lie on one image. For this reason, it must be remembered that, in observing urban areas, we are looking at surrogates of cultural and social-economic activity. The interpretation of an urban pattern derived say from North American

cities may not fit other parts of the world. Thus, in extrapolation to the case where several different cultural areas are located on a single image, allowance would have to be made for differences in patterns associated with the differences in culture.

CHAPTER III

RESEARCH DESIGN AND EXECUTION

III.1 DIVISION OF THE RESEARCH DESIGN

The research design has been strongly influenced by anticipation of multispectral satellite imagery and by the extent of literature dealing with pattern recognition of multispectral data. The design intends to follow in general the application of pattern recognition to multispectral data as reported in the literature. By so doing the author has sought to explore the intricacies of these techniques and concepts particularly in looking at urban scenes since pattern recognition of urban land use is an area of application which has not been widely investigated.

The research design then can be broken into four general sections. These are:

1. Selection and obtaining imagery of the desired areas. This includes selection of a land use classification scheme and representative sample areas.

2. Feature extraction from the designated sample areas including separation of the spectral information and transformation to a digitized array.

3. Registration of the digitized imagery and compilation of the digitized features for statistical analysis.

4. Statistical analysis of the extracted features.

III.2 SELECTION OF IMAGERY AND CLASSIFICATION SCHEME

The choice of the Knoxville region has been discussed previously in Section I.3 and is assumed to be given at this point. The land use classification scheme was modeled after a tentative classification scheme proposed by James Anderson for use with orbital imagery (1). The scheme was intended for land use mapping at the scales of 1:250,000 to 1:2,500,000. At these scales the classification is necessarily broad. The non-urban uses included in this study were: (1) cropland and (2) forest. The urban land uses were broadly divided into: (1) Industrial; (2) Commercial, and (3) Residential. A fourth urban category of "other livelihood" was not used in the study as this was felt to be a catchall for areas not otherwise identifiable. Thus, it would not be applicable in a study where areas were selected on the basis of known land uses. When this thesis began in the fall of 1972, ERTS imagery of the Knoxville region was not yet readily available. For this reason it was decided to simulate satellite imagery with high altitude photographic imagery. After some investigation, it was deciced to obtain photographic imagery from an Air Force photographic mission flown over Knoxville in April 1972. That mission was in support of NASA activities. The decision to forego the creation of imagery using the Graduate School of Planning's equipment was based on limitations of the University of Tennessee's aircraft and equipment. The University of Tennessee's aircraft has altitude limitations which restrict it to

below 10,000 feet. The Air Force/NASA imagery was recent and higher altitude, 60,000 feet. Orders for the imagery were placed with the EROS Center, Sioux Falls, South Dakota. For several reasons beyond the author's control, there was a four month delay before delivery could be made. During this period of time, duplicates of the imagery were obtained on a short loan from the Tennessee Valley Authority's Chattanooga office. The imagery was color infrared and standard color 9 in. by 9 in. format, transparencies at a scale of 1:120,000. See Figure 2 for mission parameters regarding the imagery.

As the imagery obtained from TVA was a short loan and was too large in size for the feature extraction process on a scanning microdensitometer, it was duplicated in a 1:1 scale on 8 in. by 10 in. and 4 in. by 5 in. duplicating film (see Appendix, Figure 10). For this purpose the author used the University of Tennessee, Graduate School of Planning Research Center's dark room facilities. The duplication was made onto Kodak S03 transparency duplicating film. The duplication was effected by placing the imagery to be copied on the copy film, emulsion to emulsion. The Durst enlarger was used to provide a light source of measured intensity and duration. The films were developed using the Kodak E-3 process. After some experimentation with filters, a color balance for the duplicates was approximately derived. Due to vagaries of color processing, the balance differed slightly from duplicate to duplicate. For this reason, all feature extraction operations, quantifying, were carried out on the same film piece.

In selecting sample sites, radiometric distortions caused by sun

Date of Imagery Creation: 18 April 1972

Mission Number: 197

Site Number: 177

Frame used in this study: Roll 25 number 0095

Altitude: 60,000 Feet

Time of Day: 1704 Greenwich Mean Standard

Camera: RC 8/4

Image Format: 9 in. by 9 in.

Focal Length: 6 inches

Scale: 1:120,000

Filters: Wratten 12 (minus blue)

Only technical problem of note from the mission log was failure of a recording clock on a secondary camera.

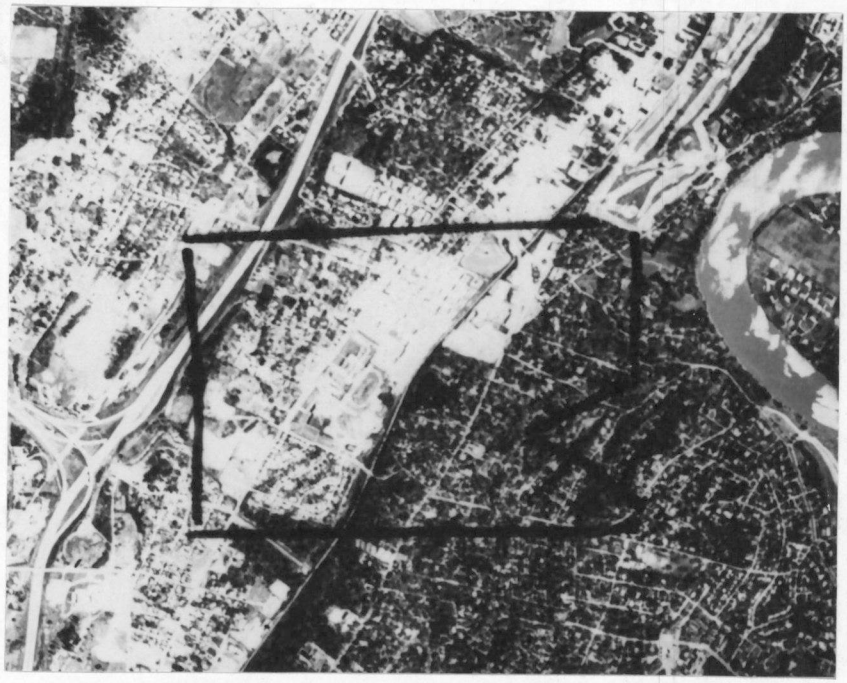
Figure 2. USAF photographic mission record.

angle, angle of reflection, atmospheric absorption along the transmission path and increases in contrast caused by the duplication process were of concern and were taken into consideration. To minimize variations due to these causes the choice of sample sites was limited to a 45 degree sector and a total radial variation of two inches from the center of the photo. The sample areas selected are indicated on the accompanying 4 in. by 5 in. transparency and are shown in black and white in Figure 3. It was recognized that there would be a degree of arbitrariness in the selection of sample sites. A prime selection criteria was that the sample sites should be in the designated sector. The commercial sample site is the Bearden Shopping Plaza and immediate environs. The industrial site is the Rohm and Haas chemical plant with associated rail lines and streets. Because of obvious differences in foliage between various residential areas, two residential sample sites were selected. These two appeared to represent a range in terms of the amount of over hanging tree foliage. One of the two residential areas, designated R1, is located to the north of the Bearden Shopping Center and the other, designated R2, is located slightly to the south as indicated on the film sample. The forested and agricultural areas were selected as lying next to each other just north of the other areas.

With the exceptions of being in the same general sector and the residential areas where apparent differences in foliage cover were a part of the selection criteria, the major selection criteria was land use. In each case the size and relative positioning of the window to

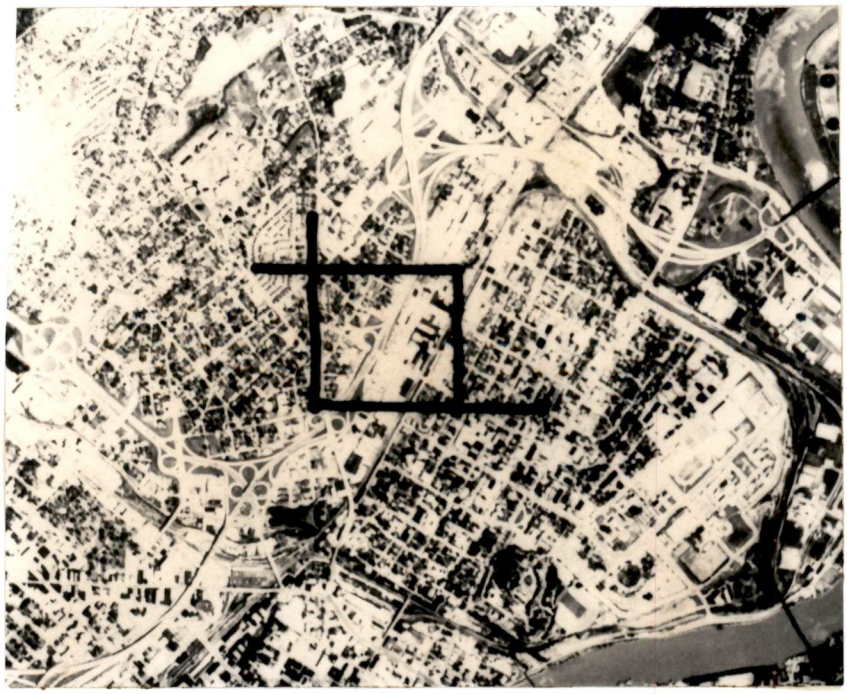


Residential Area 1 Agricultural and Forested Areas



Commercial Area Residential Area 2

Figure 3. Black and white photography of color infrared imagery showing scanned areas.



Industrial Area

Figure 3 (Continued)

be scanned were arranged so as to include prominent features, such as street and highway intersections, as location control points.

III.3 FEATURE EXTRACTION

Feature extraction or quantification is normally accomplished by one of two techniques: by the sensor itself as in the case of scanners or, in the case of photography, by scanning the imagery with an optical density measuring device. In the case of multispectral studies there are two problems in feature extraction: (1) separation of the spectral responses; and (2) the transforming or measurement of these responses or characteristics to some symbolic or arithmetic form. This second part may be equated with the actual digitization or quantification.

There are two photographic processes which are suitable for multispectral quantitative evaluation (23). The first technique is termed multiband photography. It involves the use of different black and white films with filters for simultaneous photography of the same terrain scene in several different wavelength bands. A wavelength band is composed of all the wavelengths within some limits and physically may be equated with a particular color. Most often the spectral bands used in photography correspond to the primary colors: red, green and blue. The product of multiband photography is a separate black and white emulsion photo for each wavelength band. The second method simply involves the use of color or color infrared film. Color film is a multi-emulsion film composed of three emulsion layers, see Figure 4. Each of these emulsions responds to a different part of the spectrum, principally the primary colors: red, green and blue, see Figure 5.

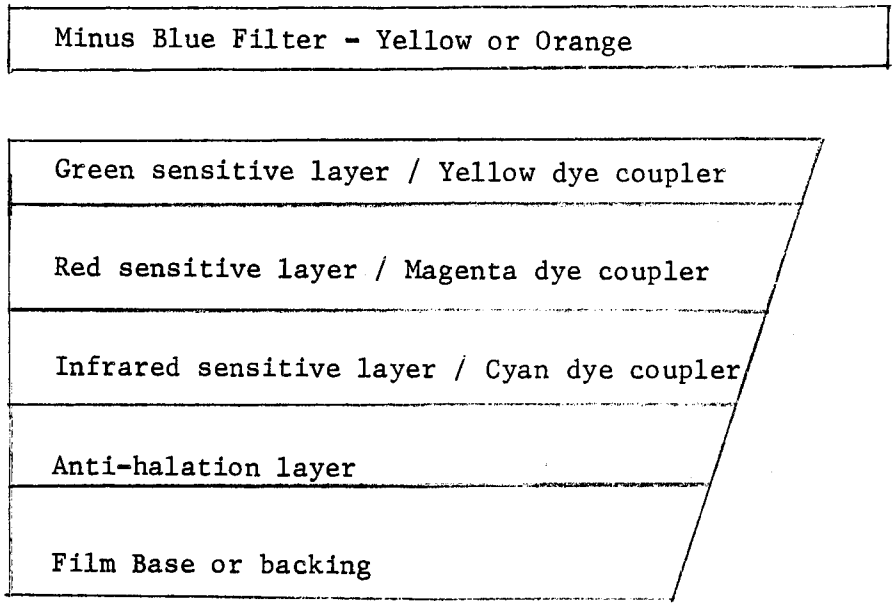


Figure 4. Cross section of Kodak Aero Infrared Ektachrome film.

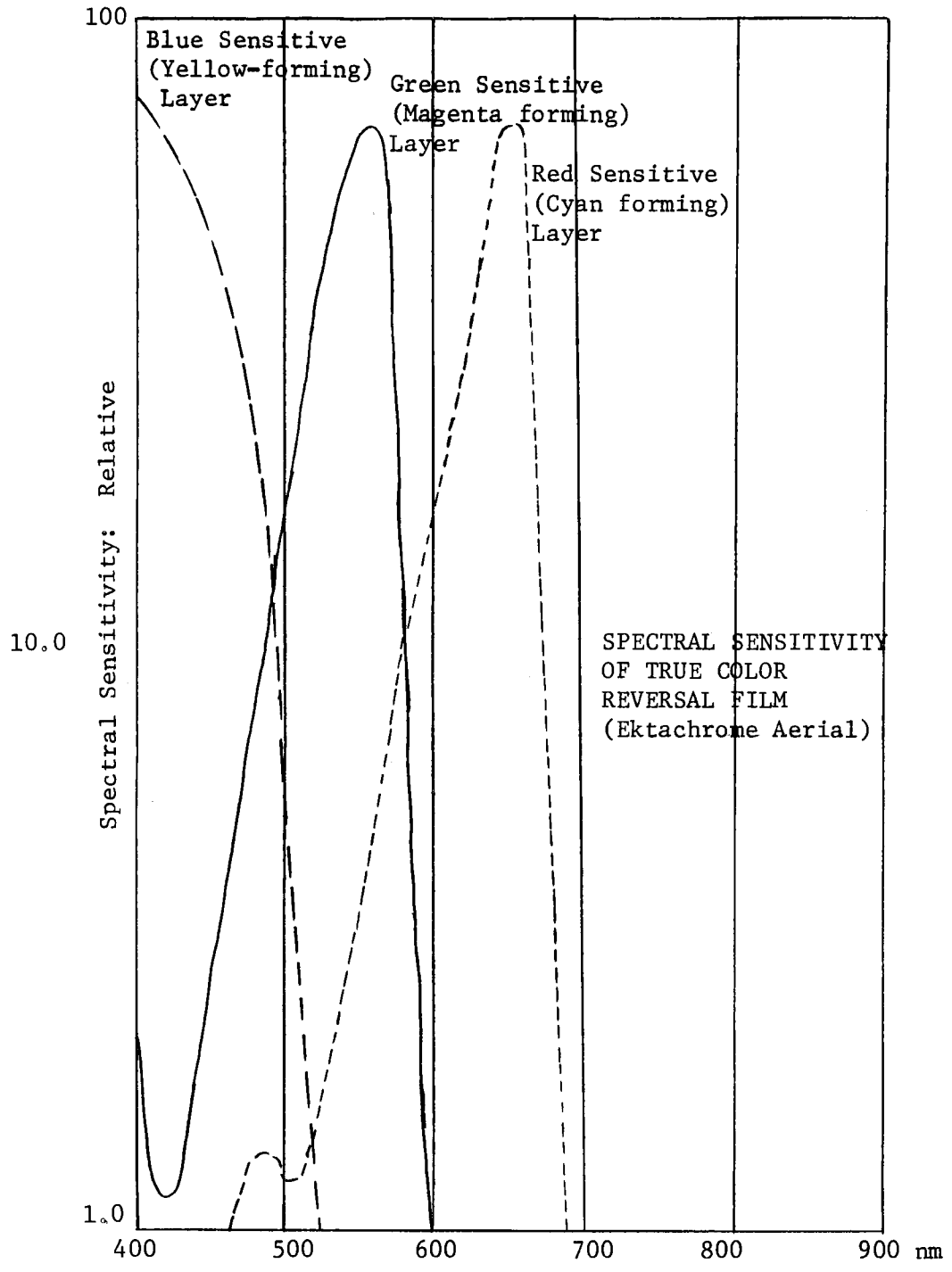


Figure 5. Graph of emulsion spectral response in color film.

Source: R. G. Trakington and A. L. Sorem "Color and False Color Films for Aerial Photography," Photogrammetric Engineering, XXIX, 1 (1963), 88-95.

Infrared film acts by extending the film sensitivity slightly past the limits of the visible spectrum into what is called the near infrared. This can be done in black and white or in a color image. Where color is used the blue part of the spectrum is filtered out by use of a minus blue filter such as yellow. The sensitivity of each of the three emulsions is shifted slightly toward the longer wavelengths, i.e., red, see Figure 6.

There are several advantages and disadvantages to the two processes. With multiband photography, it is possible to create a sharper definition of the spectral bands and therefore a greater number of divisions of the spectrum. Multi-emulsion films, on the other hand, are limited to three spectral bands and these are correspondingly wider than those of multiband photography. However, in a paper by Hoffer, Anuta and Phillips a comparison of results obtained from a pattern recognition experiment on crops using these two techniques gave the multiband method only a slight overall advantage in accuracy (23). A major disadvantage of multiband photography lies in the slight differences in areal coverage between the images caused by minute differences in rotation, and translation of the cameras inherent in the use of separate cameras. Moreover, the use of separate lens creates radiometric differences in the several images due to optical differences between lens. Multi-emulsion film by comparison eliminates most of these problems as it is a single image.

In this study, use was made of the University of Tennessee, Department of Engineering's scanning microdensitometer for the process

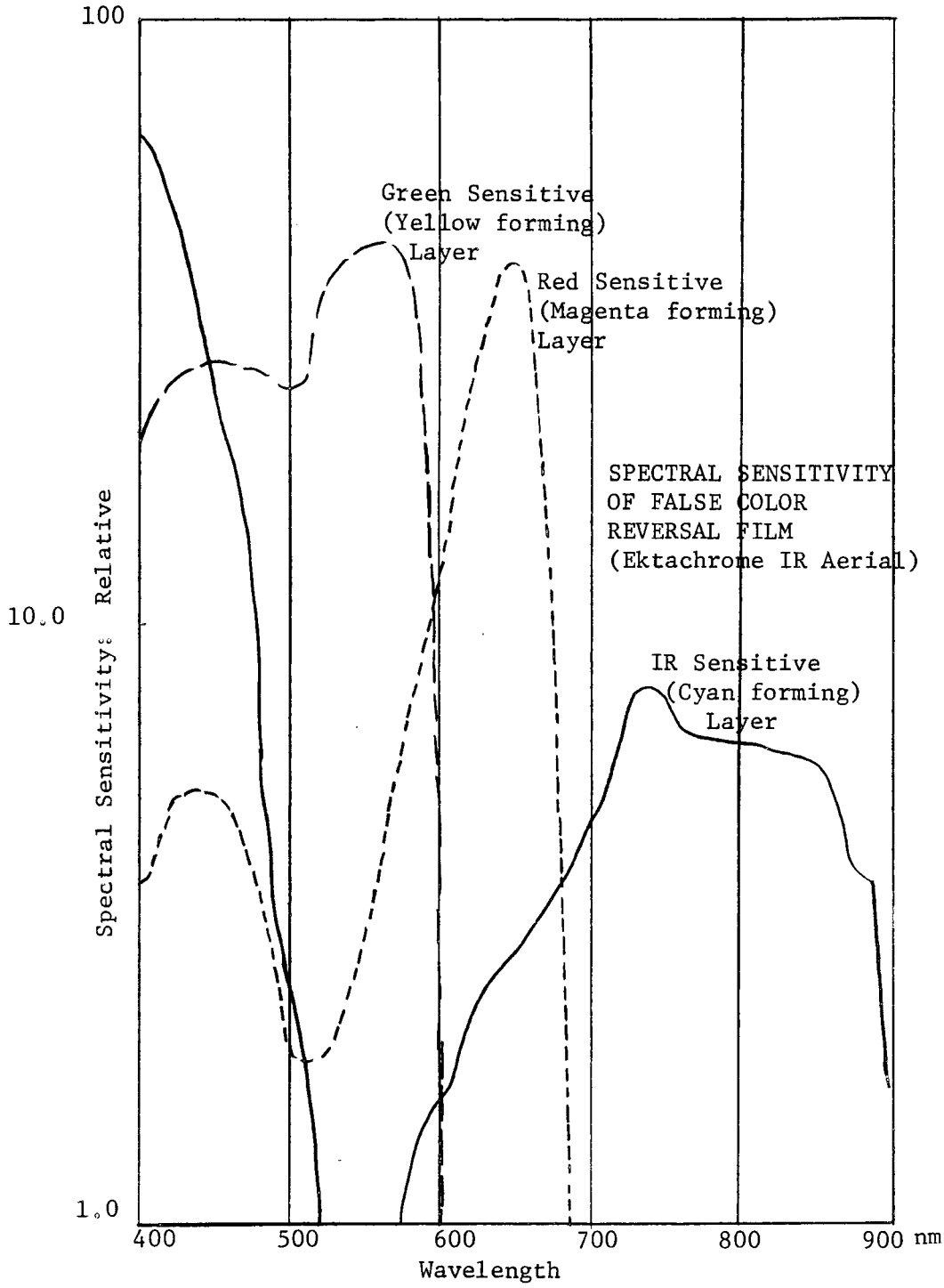


Figure 6. Graph of emulsion spectral response in color infrared (false color) film.

Source: R. G. Tarkington and A. L. Sorem "Color and False-Color Films for Aerial Photography," Photogrammetric Engineering, XXIX, 1 (1963), 88-95.

of digitization. The scanning microdensitometer is a Tech/OPS Scandig Model 25 and was purchased through the Civil Engineering department for the remote sensing program. In operation, the photographic specimen is mounted over a square window on a rotating drum. The window is illuminated by a calibrated light source from inside the drum. A microscope objective images the illuminated portion of the photographic specimen through a scanning aperture. The light transmitted through the aperture is measured by a photo-multiplier tube. The output signal of the photo-multiplier tube is, in turn, coupled via a logarithmic amplifier to an 8-bit analog to digital converter. The converter output is recorded on an eight track tape recorder as successive binary numbers proportional to the optical density at the points sampled (pixels). Any systematic drift in measuring is eliminated by automatic zeroing of the instrument at the start of each line. The microdensitometer measures optical density up to 3D--complete opacity--in some 256 levels with an optical density resolution of 0.012D. The pixel size is set at 25, 50, or 100 microns (μ) by the aperture size. The scanning in the x-dimension is accomplished by rotating the drum rapidly. At its highest rate, smallest aperture, the Scandig digitizes data at 20,000 data points per second. Scanning in the y-dimension is automatically accomplished by a screw which moves the photo-multiplier assembly down the drum. The start and stop limits in the x-direction are determined by counting pulses from an incremental shaft encoder. These limits once set remain constant. The start and stop in the y direction are determined by the number of turns of the screw. The

start must be reset for each image scanned and so results in slight differences for the point of start and stop of different scans. The major difference between multiband and multi-emulsion in feature extraction of multispectral data using a microdensitometer lies in separating the spectral bands. In multiband photography the band separation is already complete with each spectral band represented by one photograph. The process of digitization then requires only that each photograph be counted and scanned. The major difficulties arise from the misregistration of images during mounting. Each input vector for classification of multispectral data must be composed of information from the same spatial point or pixel. It is almost impossible to accurately register the images in the process of scanning because of technological limitations. In multi-emulsion photography, the image, there being only one, is mounted only once. The process of band separation is accomplished by the use of filters in the scanning microdensitometer's light beam. The filters used in the Scandig microdensitometer are: (1) red--Wratten No. 92, (2) Green--Wratten No. 93, and (3) Blue--Wratten No. 94. The problems of registration are considerably less for multi-emulsion film as the imagery remains mounted between scans when the filters are changed. The x-direction start and stop are unchanged and only the y-direction start must be reset.

In preparation for scanning, each site was outlined in black photographic masking tape. By so doing, the sample area was more exactly delimited for both the microdensitometer operator and the author. After scanning, the interior edges of the tape were recorded on a separate transparency which was maintained as a permanent record.

Once the scanning microdensitometer had digitized and recorded the image on magnetic tape, it was necessary to present the data in a usable form. It is possible to work with the digitized information directly from the magnetic tape. However, such work requires a facility with computer programming which the author did not possess at that time and did not have the opportunity to attain. Rather, the digitized images on tape were printed out on the computer's high speed printer using an Electrical Engineering Department computer program designated "OPSCAN." The "OPSCAN" program was designed to read the binary pixel density levels off magnetic tape, calculate the optical density statistics for the entire scanned area, translate each density measurement to some number or pictorial grey tone and then print out that information in pictorial form. The program has a number of controls by which the pictorial printout could be enhanced as an aid for interpretation including: edge enhancement, thresholding, establishing density levels and creating special overprint characters for semigrey tones.

Prior to beginning the digitization of sample areas, a test run was made on another area for the purposes of determining difficulties in locating specific points and comparing the differences in scanning with different size apertures. A section of the transparency corresponding to the area of I-75 from the I-40 junction north to Clinton Highway was scanned in all three bands at 25 microns and at 100 microns. The following difficulties and observations were realized in the two step process of digitization and computer print out of the digitized imagery:

1. The OPSCAN program as then existing was not designed to handle the large numbers of pixels associated with digitization of large areas and therefore required relatively large amounts of IBM 360/65 CPU time. CPU time is the amount of time a computer is actively handling data in its central core and at that time was valued at $150 per hour. In the trial run, time limits were estimated to be upwards of one hour.

2. The scanning process, because of the devices used, results in a rectangular area being scanned. For this reason, it is desirable that windows being scanned be rectangular and oriented with the edge of the photograph. Where the target area is oriented other than as the scanning "window," large portions of the border are included in the scan. The borders having been masked off by tape there was no usable information there.

3. The large CPU times resulted in low priority for access to the computer and a waiting period of several days to a week between job submittal and completion was not unusual.

4. Comparison of the different bands suggested that the infrared band was best suited for human location of areas and boundaries. The presence of large paved areas such as interstate highways with grass shoulders greatly aided in determination of location. This was attributed to the high reflectivity of vegetation and relatively low reflectivity of paved areas in the infrared.

5. Comparison of the statistics for the infrared band were made between the scans at 25 microns and 100 microns. The comparison

indicated a substantial decrease in densities. This would seem to be similar to the effect reported by Doverspike, Flyn and Heller in Photogrammetric Engineering, March 1965 (13). They reported an exponential decrease in apparent density as aperture size was increased.

In the subsequent digitzation of sample areas, the difficulties and observations made above were taken into consideration. The following rules were observed:

1. Scanned areas were kept to a minimum, 1-1/2 cm. by 1 cm being the largest. This was sufficient area to permit identification and location of the sample sites.

2. Where possible, interstate highway or major streets were included to serve as reference control points.

3. Areas to be scanned were rectangular and oriented along the axis of scanning.

4. The digitized areas were printed out with the first file, infrared, being full scale: that is, every pixel was listed. The second and third files were printed at 1/3 scale. Every third line and every third column were printed out. This substantially reduced the computer time required for execution.

5. All subsequent scanning of sample sites was at a 25 micron aperture. The smaller aperture, it was felt, gave a sharper definition of boundaries for human interpretation. The 25 micron aperture at a scale of 1:120,000 gives a ground resolution of approximately 9.5 feet in diameter. Moreover, the smaller aperture would give a lower percentage of pixels containing two or more different targets.

III.4 REGISTRATION AND COMPILATION OF EXTRACTED FEATURES FOR STATISTICAL ANALYSIS

Scanning the sample sites was accomplished in two runs. In the first run two windows, consisting of a residential area and an industrial area, were recorded on tape 1974. The second run, also consisting of two windows, was recorded on tape 02230. The first window was of forest and agricultural areas. The second window was an urban site containing commercial and residential areas.

After printouts of the areas were secured, it was necessary to determine registration and locate the selected sites. As mentioned previously, scans in the direction of drum rotation remained constant. In the y-direction, corresponding to the direction of photo-multiplier assembly travel, the necessity of reseting the start point led to differences in registration. The determination of registration was relatively simple in most cases: it being necessary only to observe where the masked boundaries were located. There were, however, two exceptions:

1. Several boundaries were somewhat indistinct with the darker masked areas appearing to be carried irregularly out into the actual picture. This was attributed to "overshoot" by the photo-multiplier assembly. "Overshoot" being that where a very dark and very light area are abutting, the finite time required for the detector and associated electronics to change from one extreme electrical state to another as the observed point is moving beneath results in a false

reading. Fortunately this only occurred as the scan went from dark to light and the other boundaries were not affected.

2. Registration of the industrial scan, particularly the blue band, on tape 1974 proved especially difficult because the masking boundaries were not tightly sealed along the edges. Tests in other areas showed that properly registered sample sites, predominantly of one land use, when preprocessed as a ratio, had approximately a normal distribution. Working under the assumption that only the y-axis was out of registration, a computer program, "Reitter," was written by the author. Reitter took a line of pixels in the y-direction from each of the three bands. The lines were already registered in the x-direction. The line representing the center band, green, was then repeatedly moved between the two other lines. At each move a new ratio was formed between each pixel and its neighboring pixel in the next band. Histograms of the resulting distributions were made by the same computer program. By simple inspection of the distributions, it was possible to locate the point of registration.

After determining the proper registration, the areas selected as sample sites were located on the window printouts. Location of the sample sites was accomplished by interpretation of the infrared band printout. Major streets and highways, such as interstates, were used as control points from which other locations could be determined. Once the same point could be located on each band, a sampling grid was set up on the infrared band. The grid was located in the sample site and two hundred samples for each sample area were extracted and recorded by hand.

The points sampled from the infrared band were also extracted from the green and blue bands. All three density levels for each point were recorded together in a book set up for that purpose. Later this information was punched onto cards as the data for statistical testing. The sample size of two hundred per sample category was determined on a relatively arbitrary basis. The primary considerations were:

1. That a sample of two hundred per category was sufficiently larger than the minimum thirty suggested by most statistics texts as necessary to approximate the parent population in a parametric test.

2. A total sample size of 1200 (200 subjects per sample with six sampled areas) was small enough to be handled by hand without errors in transferring the data.

3. That the area covered by 200 subject samples was able to fit within the selected sample areas while allowing the sample points to be set approximately 18 feet from center to center. This latter condition reduced the possibility of counting a small target twice.

CHAPTER IV

STATISTICAL HYPOTHESIS TESTING

IV.1 STATISTICAL TECHNIQUES: METHODOLOGIES AND APPLICATION

In this study there were three techniques applied to analysis of the compiled data. These were: the Hotelling "T Squared" test of multivariate equal means; a hierarchial clustering of the sample pixels based on minimum distance concepts; and a stepwise discriminate analysis of the variables. The Hotelling "T Squared" test was the major proof of the research hypothesis. The other two techniques were used for their aid in exploring several consequent questions. First of these subsequent questions was which of the radiometric bands seemed to give more information in terms of separating the sampled sites. Second, given that each sampled area was made up of disparate targets some of which were common to all the sampled areas, how many distinct categories could be differentiated from an aggregation of the areas. The BMD07M stepwise discriminate analysis and the HGROUP statistical packages were available and were respectively applied to these questions.

IV.2 APPLICATION OF THE HOTELLING T SQUARED STATISTICAL TEST OF MULTIVARIATE EQUAL MEANS

The choice of the "T Squared" statistic was recommended on the basis of the research hypothesis and its possible applications. That is,

the use of the means as the statistic of comparison would more closely approximate the case of comparing pixels from space imagery. This being one purpose towards which the research hypothesis is directed. The major difference lies in the scale and resolution between space imagery and the photographic imagery used here. By use of the arithmetic mean of the smaller photographic pixels it is arguable that we can approximate a parent population represented by a space pixel, the space imagery pixel being the result of an integration over some area.

Intuitively it seems proper that the more difficult condition be imposed when testing the hypothesis so as to provide a more conservative answer. The use of preprocessing might be necessary as described previously to offset radiometric biases. As noted previously, preprocessing results in a loss of information. Thus there is a trade off between the stability of a spectral signature and the amount of information derivable from remote sensor imagery. By conducting the test on the preprocessed data, a more conservative answer could be derived.

Hypothesis testing using the "T Squared" statistic follows the normal procedures of inferential statistical testing. The research hypothesis, H_1, as previously stated, was that the sampled areas were sufficiently different in spectral characteristics to be differentiated on that basis. A null hypothesis, Ho, was formed to the research hypothesis, the null hypothesis being that there were no significant differences between the sampled areas. By comparing the multivariate means of the spectral bands through use of the "T Squared" statistic it would then be possible to accept or reject the null hypothesis.

Rejection of the null hypothesis would be a strong indicator of the validity of the research hypothesis.

The use of the inferential approach in this study is justified on the basis of the complexity of construction and testing a complete pattern recognition system. Proof that different areas can be differentiated through the use of spectral characteristics does not necessarily prove that like but spatially separate areas can be identified on the same basis. However, any pattern recognition system when tested would render a percent of right or wrong decisions and not a discrete right or wrong solution. The degree of right or wrong would be determined by both the system mechanics and the concept's validity and would hence not necessarily constitute a complete proof of the hypothesis, i.e., the concept's validity. Thus the use of inference with less mechanism would seem justifiable.

As with all statistical tests, there are several assumptions inherent in use of the "T Squared" test. These are:

1. The assumption of random sampling.

2. An assumption of a multivariate normal distribution.

3. The assumption of at least an interval level of data measurement.

The "T Squared" test's actual mechanics were taken from Donald F. Morrison's Multivariate Statistical Methods (30).

While the "T Squared" test for multivariage means could handle any number of variables, it was chosen, for this study, to reduce the number of variables from three to two. This was done in the

preprocessing of the data. In practice, preprocessing meant that for each spatial point the three spectral values, red, green and blue, were transformed to two ratios: red/green and green/blue. It was from these ratios that the "T Squared" statistic was formed.

In calculation of the "T Squared" statistic, two computer programs were used. The first of these, "Opfile," took the pixels compiled from semi-grey tone symbols on the digital image printouts and translated these back into their arithmetical equivalents. The values had a possible range of 1 to 255, that being the number of grey levels the scanning microdensitometer could differentiate. The "Opfile" program then printed out the distribution of the red/green and green/blue distribution in histogram form and calculated the sums of squares, means and summed cross products for each sampled area. Histograms of the distributions are shown in Table 1 and Figure 7. A second computer program "Statistic" then calculated the "T Squared" or "F" statistic between each sampled area and all other sampled areas. A "T" statistic when squared as was done in this test is the equivalent of the "F" statistic which typically is looked up in a set of tables rather than computed from theory. The resulting "F" values are displayed as a matrix in Table 2.

A standard maxim of inferential statistics is to be relatively conservative in proffering statistical proof of a research hypothesis. In light of the research objectives of this thesis, it was decided to minimize type I error. That is, it was chosen to minimize the probability of saying there is a statistically significant difference

TABLE 1

STATISTICS ON PREPROCESSED DATA

Test Group	Forest		Agriculture		Residential 1		Residential 2		Commercial		Industrial	
Variable	R/G*	G/B**	R/G	G/B	R/G	G/B	R/G	G/B	R/G	G/B	R/G	R/B
Mean	0.888	1.308	0.529	1.367	0.838	1.117	0.877	1.370	1.199	1.337	1.269	1.317
Std. Error	0.008	0.007	0.011	0.008	0.011	0.014	0.014	0.370	0.013	0.013	0.010	0.008
Median	0.899	1.318	0.469	1.378	0.819	1.099	0.848	1.326	1.186	1.356	1.259	1.325
Mode	1.000	1.331	0.451	1.355	0.832	1.000	1.000	1.326	1.000	1.389	1.290	1.310
Std. Dev.	0.117	0.094	0.155	0.116	0.161	0.205	0.193	0.520	0.179	0.185	0.141	0.117
Variance	0.014	0.009	0.024	0.014	0.026	0.042	0.037	0.271	0.032	0.034	0.020	0.014
Kurtosis	-.021	-.847	6.376	25.182	44.885	5.239	-.149	54.876	7.624	2.712	19.483	9.440
Skewness	-.430	-.403	2.440	-3.642	5.233	0.815	0.585	11.833	1.883	-1.015	2.718	-1.583
Range	0.618	0.542	0.943	1.237	1.878	1.784	0.907	7.423	1.424	1.227	1.423	1.090
Min.	0.522	1.029	0.368	0.490	0.531	0.419	0.520	0.867	0.779	0.581	0.987	0.529
Max.	1.139	1.571	1.312	1.727	2.410	2.204	1.427	8.289	2.203	1.807	2.409	1.619

*R/G = Red/Green
**G/B = Green/Blue

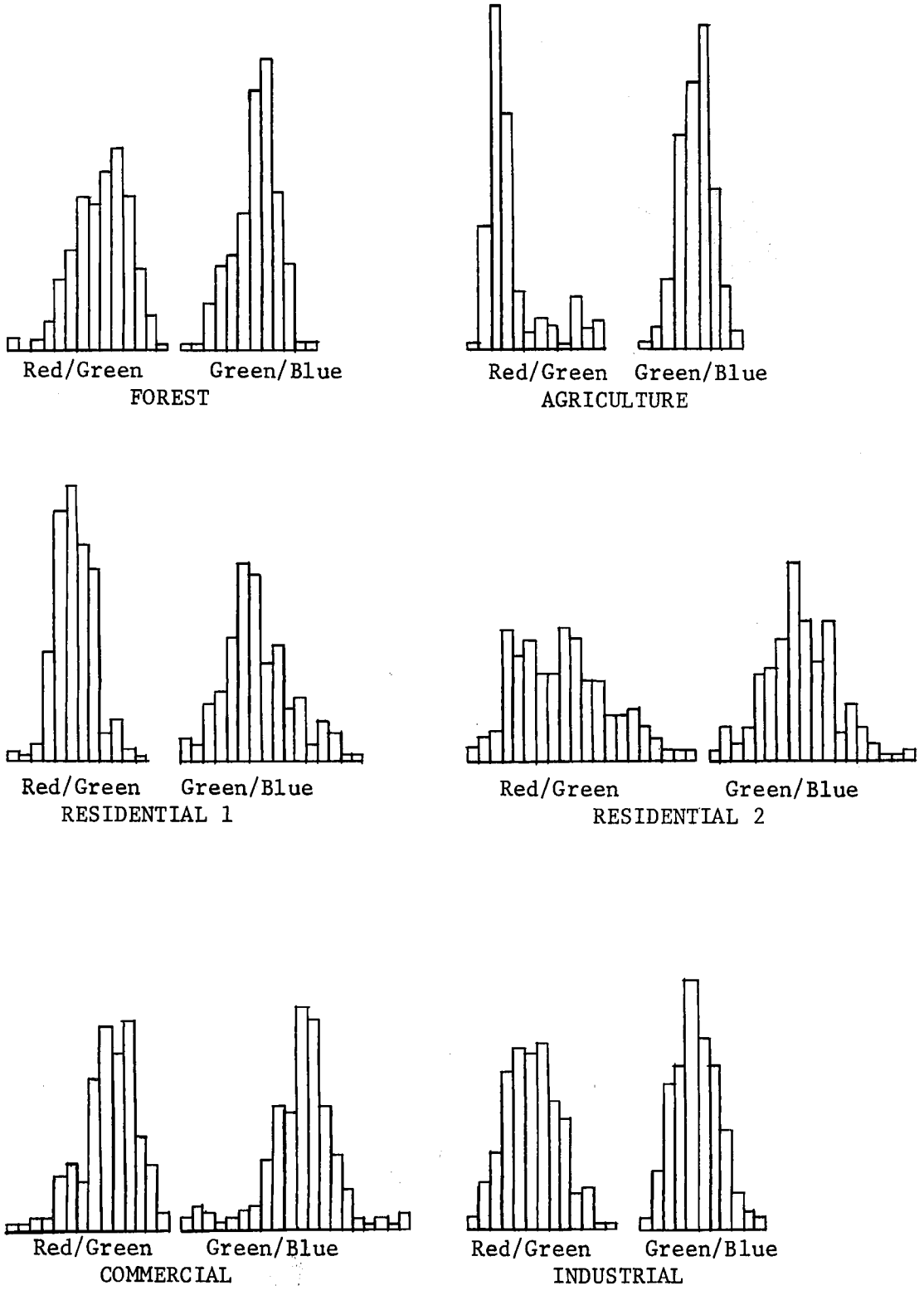


Figure 7. Histograms on statistics of digitized data in the preprocessed form.

TABLE 2

MATRIX OF F STATISTICS FROM HOTELLING T^2 TEST

	Forest	Agriculture	Residential 1	Residential 2	Commercial	Industrial
Forest	0.0	519.4	72.1	1.77	236.9	433.0
Agriculture	419.4	0.0	519.0	203.4	1225.0	1425.0
Residential 1	72.1	419.0	0.0	20.9	225.0	412.8
Residential 2	1.77	203.4	20.9	0.0	163.0	277.1
Commercial	236.9	1225.0	225.0	163.0	0.0	14.8
Industrial	433.0	1425.0	412.8	277.1	14.8	0.0

between the sample areas when there isn't. This was accomplished by testing with alpha, the level of statistical significance, set equal to 0.001. Minimization of type I error carries the penalty of proportionately increasing type II error, that of saying there is not a statistically significant difference when there is.

In the normal manner of statistical testing, the null hypothesis of equal means is accepted if the test "F" statistic is less than or equal to the tabled "F" statistic given for a determined number of degrees of freedom and a predetermined level of statistical significance. Where the test statistic exceeds the theoretical statistic in the tables, the null hypothesis is rejected in favor of the research hypothesis. For the "T Squared" test, the degrees of freedom are equal to K and N1 + N2 - K - 1 where K = the number of variables and N1 and N2 = the number of subjects sampled in each group. This was respectively K = 2 and N = 397 degrees of freedom. The value of the "F" statistic for 2/397 degrees of freedom at the 0.001 level of statistical significance is 7.3. The "F" statistic may also be considered as a relative indicator difference, i.e., 100 is greater than 50. Table 3 indicates where there were statistically significant differences and the degree of difference.

IV.3 APPLICATION OF STEPWISE DISCRIMINATE ANALYSIS OF THE SPECTRAL BANDS

The BMD07M program is one of a series of computer programs for statistical analysis created by the Biomed Group of UCLA (12). The

TABLE 3

INDICATION OF SIGNIFICANCE OF HOTELLING T^2 TEST

	Forest	Agriculture	Residential 1	Residential 2	Commercial	Industrial
Forest	-	**	*	-	**	**
Agriculture	**	-	**	**	***	***
Residential 1	*	**	-	*	**	**
Residential 2	-	**	*	-	**	**
Commercial	**	***	**	**	-	*
Industrial	**	***	**	**	*	-

*Significantly different.

**Very significantly different.

***Extremely significant.

-Not significantly different at 0.001 probability level.

program performs a discriminate analysis on a multivariate data set in a stepwise manner. At each step, one additional variable is entered into the discriminating set of variables. The discriminate analysis is similar to the T Squared test in that it produces a matrix of F statistics indicating the statistical probability of similarity between the sampled groups. It differs in that it calculates the F in a stepwise manner including one additional variable at each step. Thus it is possible to assign a degree of importance to each variable, of the n variables, used in differentiating or comparing a number of groups. "The variable entered is selected by the first of the following equivalent criteria:

1. The variable with the largest F value.

2. The variable which when partialed on the previously entered variables has the highest multiple correlation with the groups.

3. The variable which gives the greatest decrease in the ratio of within to total variances" (12).

In addition to comparing the multivariate means of groups, the BMD07M program also considers the membership of each group and reassigns group members on the basis of maximum likelihood principles. This is basically a simplified pattern recognition which uses the group membership statistics to compare the membership.

The BMD07M program was run on the compiled pixels in both the basic and preprocessed forms. The results are shown in the Appendix. The number of steps in each run--there being one run for the basic information and one for the preprocessed--is equal in each case to the

number of variables in that run. The matrix of F statistics to test the equality of group means is, in the case of the second step on the preprocessed data, similar to but not exactly the same as reported in the T Squared test. These differences are not consequential in changing the statistical significance and are attributable to slight computational and rounding differences between computer programs.

IV.4 HIERARCHIAL CLUSTERING OF THE COMPILED DATA

In Chapter II, pattern recognition was described in terms of discriminate and clustering techniques. Discriminate analysis is the major branch which has been discussed. Clustering, by comparison, is described variously as unsupervised learning procedures in which the learning of the common properties is by grouping like together. One application of clustering techniques is to help organize the data in such a form as might aid the researcher in the process of discovery. The program used, HGroup, was created by D. J. Veldman (55) and was modified to the form used here by Professor Dieter Steiner, University of Waterloo. The program, HGroup, accepts the data input as separate entities or centroids and then in a sequential manner aggregates those centroids on the basis of minimum distance. At each step, all existing centroids, whether a group or a remaining individual, are compared. Those two centroids which are closest on the basis of minimum increase in variance of the euclidean distance between members are aggregated together as a single controid. Some care must be made in relying on this technique as a single measure of distance is used and this can

obscure possible differences within a variable. This method is primarily descriptive of the data in a sample and there is no statistical basis for inferring the stability of results to other samples.

Therefore, the determination at which step the grouping is best is intuitive and relatively arbitrary. There are several different options or guides possible. The first is to graph the within variance for all groups versus the number of groups remaining. A sharp increase in variance can be interpreted as a possible aggregation of dissimilar groups. A second method is to make an a priori determination of how many groups there should be. The clustering technique is used only to determine the group membership and give some indication of its compactness in terms of the changing variance.

Clustering algorithms tend to be expensive in terms of computer time. For this reason, the HGroup program is written to accommodate a maximum of 100 subjects. Ninety six subjects, sixteen randomly selected from each of the six sample sites, were actually used. The number of groups versus within group variance is shown as a graph in Figure 8. The group membership is shown in Table 4 and Figure 8 for two steps, the first being a relatively sharp increase in variance and the second being when the clustering reached six groups. A duodenogram is included as Figure 9 showing the combining of groups down to the step with two groups remaining.

IV.5 DATA ANALYSIS

Inspection of the F statistic matrix from the Hotelling T

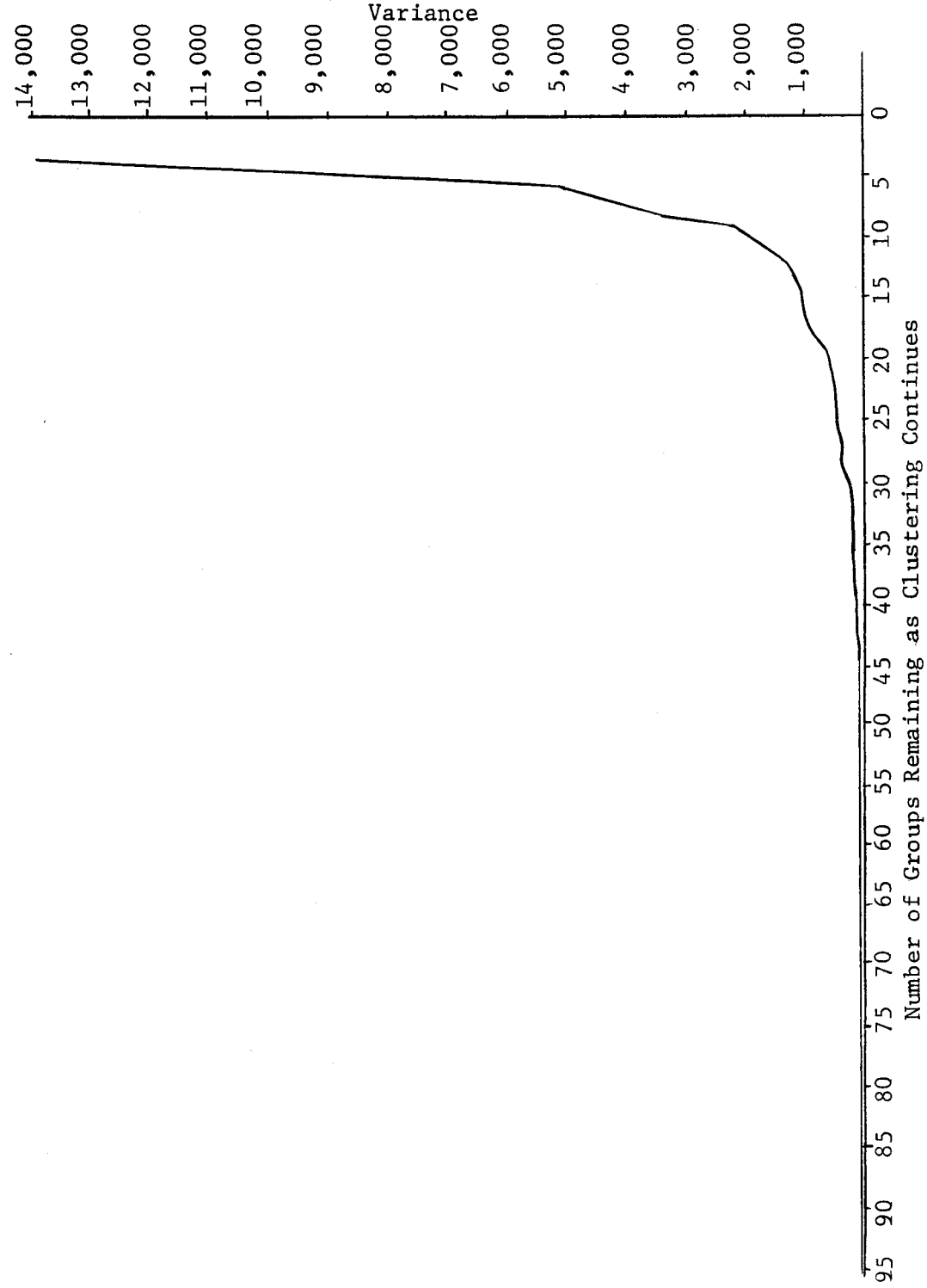


Figure 8. Plot of groups versus variance.

TABLE 4

HIERARCHIAL GROUPING

Group	Members
Group membership with 29 groups remaining, error = 264.566	
G 1 (N=2)	F-1;R1-3
G 2 (N=3)	F-2;F-3;R2-9
G 4 (N=4)	F-4;F-6;F-12;F-13
G 5 (N=5)	F-5;F-8;F-11;R2-3;R2-8
G 9 (N=3)	F-9;F-14;R2-13
G16 (N=3)	F-16;R1-12;R1-15
G17 (N=2)	Ag-1;Ag-16
G18 (N=9)	Ag-2;Ag-3;Ag-4;Ag-5;Ag-7;Ag-8;Ag-10;Ag-13;Ag-14
G22 (N=4)	Ag-6;Ag-9;Ag-11;Ag-12
G31 (N=3)	Ag-15;Ind-4;Ind-5
G33 (N=4)	R1-1;R1-5;R1-6;R1-10
G34 (N=5)	R1-2;R1-4;R1-7;R1-8;R1-9
G43 (N=2)	R1-11;R2-4
G45 (N=2)	R1-13;R1-14
G48 (N=2)	R1-16;Com-2
G49 (N=5)	R2-1;R2-5;R2-6;R2-11;R2-16
G50 (N=1)	R2-2
G55 (N=1)	R2-7
G58 (N=4)	R2-10;R2-14;Com-7;Com-12
G60 (N=1)	R2-12
G63 (N=3)	R2-15;Com-1;Com-13
G67 (N=7)	Com-3;Com-4;Com-8;Com-9;Com-10;Com-11;Ind-9
G69 (N=4)	Com-5;Com-6;Ind-11;Ind-16
G78 (N=1)	Com-14
G79 (N=1)	Com-15
G80 (N=2)	Com-16;Com-15
G81 (N=6)	Ind-1;Ind-2;Ind-7;Ind-8;Ind-12;Ind-14;Ind-3;Ind-6
G83 (N=2)	Ind-3;Ind-6
G90 (N=2)	Ind-10;Ind-13

TABLE 4 (Cont'd)

Group	Members
Group membership with 6 groups remaining, error = 5039.1758	
G 1 (N=11)	F-1;R1-1;R1-2;R1-3;R1-4;R1-5;R1-6;R1-7;R1-8;R1-9;R1-10
G 2 (N=27)	F-2;F-3;F-4;F-5;F-6;F-7;F-8;F-9;F-10;F-11;F-12;F-13 F-14;F-15;F-16;R1-11;R1-12;R1-13;R1-14;R1-15;R2-2 R2-3;R2-4;R2-8;R2-9;$2-12;R2-13
G17 (N=21)	Ag-1;Ag-2;Ag-3;Ag-4;Ag-5;Ag-6;Ag-7;Ag-8;Ag-9;Ag-10;Ag-11 Ag-12;Ag-13;Ag-14;Ag-16;R2-1;R2-5;R2-6;R2-7;R2-11;R2-16
G31 (N-7)	Ag-15;Com-14;Com-15;Ind-3;Ind-4;Ind-5;Ind-6
G48 (N=11)	R1-16;R2-15;Com-1;Com-2;Com-5;Com-6;Com-13;Com-16;Ind-11 Ind-15;Ind-16
G58 (N=19)	R2-10;R2-14;Com-3;Com-4;Com-7;Com-8;Com-9;Com-10;Com-11; Com-12;Ind-1;Ind-2;Ind-7;Ind-8;Ind-9;Ind-10;Ind-12 Ind-13;Ind-14

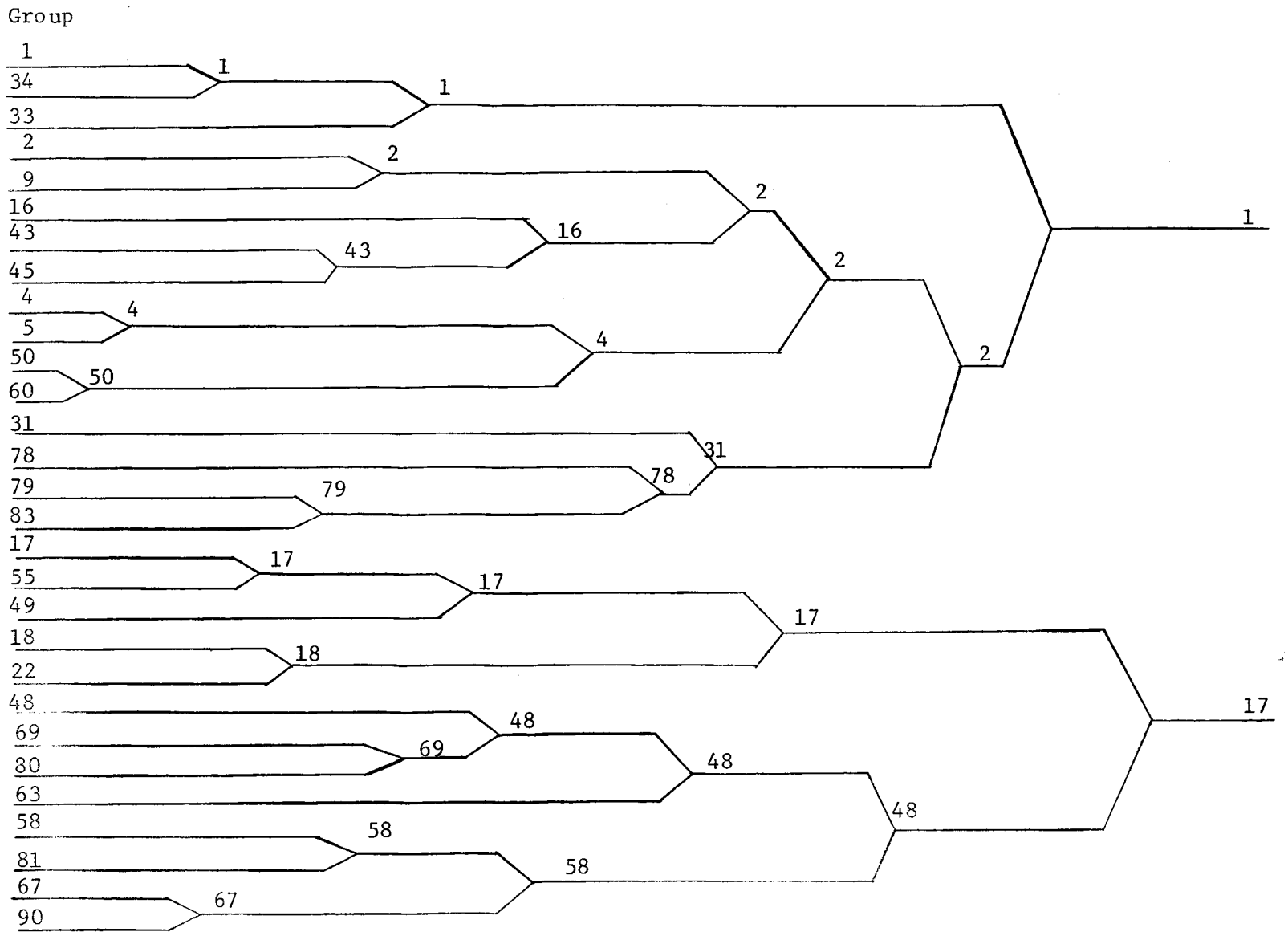


Figure 9. Duodenogram showing grouping process. Numbers are group identifiers.

Squared test reveals that at the level of significance tested, alpha = 0.001, there is a statistically significant difference between spectral signatures of the test sites in all but one case. With the one exception, the differences between groups are so great that there is less than one chance in a thousand that the differences could be the result of random error. That exception occurs between the forested area and the second residential area, R2. Inspection of the two areas, both on the photographic imagery and on the ground, reveal that much of the residential nature of R2 is hidden under a canopy of trees. Those man-made elements of a residential nature are then masked by foliage leaving residential site, R2, to resemble the forested site from the air. The ability to differentiate residential area R2 from the forested area is significantly improved when the unpreprocessed data is used. This can be seen in step 2 of Appendix. An interesting fact to be derived from the Hotelling T Squared test is the degree of difference between areas. The degree of difference is surprising given that the statistics were calculated on the preprocessed data which could be expected to produce a loss in information and a decrease in the ability to differentiate between two groups. This can be attributed to a redundancy in the information and suggests that far fewer samples than the 200 per category could be used in certain instances.

The BMD07M Stepwise Discriminate Analysis computer program, listed in the Appendix, had two interesting results. The first of these deals with the choice of which spectral band tended to have more information. As mentioned previously, this program operates in a

stepwise fashion including at each step that variable from those left, which accounts for the greatest amount of variation, F. That is, at each step the variable is chosen which can best explain the remaining unaccounted for difference. There were three variables, spectral bands, used in this study.

As the major test had been performed on the preprocessed spectral bands, the data was first submitted to the BMD07M program in this form. In the preprocessed form, the red/green variable explained the greatest amount of variance, and a F value of 602.61 was compared with a F value of 39.27 for the green/blue variable. The magnitude of difference is in part explained by looking at the analysis of the basic data. There is, from the correlation matrix of the BMD07M program, a high correlation between the green and blue variables. Hence the amount of variation that could be expected from a ratio of the two is relatively small. After investigation, it was concluded that the correlation could in part be attributed to a combination of three possible causes:

1. Central urban areas image spectrally at the 600 to 650 nanometer region. This has been reported in the literature (6).

2. The spectral sensitivity of CIR film is such that the blue and green emulsions overlap at approximately 600 nanometers. This could result in a response being recorded in both blue and green for an image in the 600 nanometer range.

3. A third possibility is that the spectral filters used in the scanning microdensitometer might have transmitted both green and blue light. This possibility is discounted to a degree as published transmission curves for those filters show them as not overlapping.

When observing the inclusion of variables in the basic form, it is the blue spectral band--variable--which is included first with the red spectral band being second. Comparison of the F statistic attributed to these two variables at the second step--this excludes the green variable--shows them to be fairly similar with red having a F value of 342.08 and blue having 481. The green spectral band is included last and shows a substantially lower F value. This would seem to be associated with the high correlation between green and blue spectral bands mentioned above. Blue, having a greater degree of explanation of the total variation, is assigned the full value which can be explained by both green and blue. Green, under this method, is assigned only that part of the total variation attributable to it. Its inclusion then does not add greatly in explaining the difference between the sampled areas. Consideration of the sensor and the imaged area gives some explanation for apparent dominance of the red and blue spectral bands. The red band corresponds to the near infrared spectral region, as mentioned in the description of CIR film. The blue band tends to cover the blue-green part of the sun's spectrum. In terms of targets imaged, inspection of CIR imagery of urban areas shows a pattern in which the outer areas are red and change to a neutral blue-grey tone in toward the central business district. As the color in any color film depends both on the target photographed and the vagaries of processing, there can be differences from image to image. A preponderance of reflection in the near infrared, which shows as red on the imagery, is associated with healthy vegetation, grasses, crops and deciduous trees. There is

some vegetation which has a spectral signature other than red. As an example, conifers, pine trees, image as blue-grey in CIR imagery. These, however, are the exception rather than the rule. In urban areas, the CBD seems to be recorded in blue-grey tones on CIR film. The surrounding areas of commercial and industrial support, including the so called "grey areas," are reported to peak at about 650 angstroms, slightly toward the red (6). The reflectance in the CBD seems likely to be associated with the larger amounts of paved areas and structures of concrete and stone. These image on CIR film as being neutral, blue-grey. Residential areas with their lawns, cultivated vegetation as well as structures and pavement have elements that peak in both the red and blue on CIR film. Cultivated fields and forest areas being vegetation reflect primarily in the near infrared--corresponding to red on CIR film. If this pattern of urban signatures is essentially correct, then the two prime variables of interest would appear to be the relative amounts of red and blue signatures on CIR film.

The second interesting result derived from application of this statistical program lies in the misclassification within groups. There are two questions which have been involved in this study. The first argued that on the basis of samples from test sites of known land uses that the case for pattern recognition of land uses from satellite imagery could be approximated and statistically proven feasible. That case used the aggregated samples to approximate the urban spectral signatures as might be recorded on satellite imagery. The second question is concerned with how alike are the sample pixels within the

same area. The BMD07M program has a feature which tests the groups presented to it in terms of maximum likelihood and reassigns members to other groups on that basis. The results are interesting but subject to several restraints. First, the decision making levels are based on the samples presented. Secondly, the number of groups is restricted to those originally presented. In some applications, this latter point may be no difficulty. In the present application, it is possible that there are one or more categories present other than those defined as being included. As an example, there may be small bodies of water, creeks and ponds, for which no explicit allowance has been made in the six test types dealt with. In such an instance, the pixel from water would be allocated to that test type which it was most like. There are two additional considerations operating on our assignment of samples to categories in this or any other pattern recognition scheme. First is the existance of differences between groups in terms of our variables, spectral signature. Secondly, there is the homogeneity of the samples from our land use types. It is very possible that some land uses would be composed of essentially the same target types, very compact in terms of distribution within the spectral range. Or it is possible that the land use type could be made up of heterogeneous types which would be more widely distributed across the spectral range.

The resulting interaction of conditions is visible in the table of "number of cases classified into each group" given for each step. The ability to discriminate between groups appears to improve from the case of using one preprocessed variable through to that of using two basic

variables. But even in the best case there is still a reallocation, or wrong grouping, of an average of 32 percent. This can be taken to mean that, for the best case, the classifying variables used, failed to sufficiently describe 32 percent of the samples. Or, some 32 percent of the samples fit into some category other than the one to which they were sampled from. Or, the misclassified type may not have been included explicitly as a category.

There are several difficulties in establishing perfectly the number of targets existing in the test sites which are both functionally and spectrally different. Some of the major problems lie in the time difference, eighteen months, between the imagery creation and the time of ground truth survey of the sites. There is a strong possibility of both environmental change and movement of man made objects. Moveover, the computer printout of imagery is not sufficiently precise in a cartographic sense to permit accurate ground location of ten foot diameter pixels.

The HGroup program does give some measure of the clusters based solely on the spectral characteristics. The program suffers primarily from the combining of all dimensions into a single measurement distance, this having the result that some differences can be lost. The clustering exercise was conducted on the basic data using all three variables as features.

The grouping results in a steady increase in error as revealed in the graph of groups remaining versus variance shown in Figure 8, page 59. The group memberships are shown at two points. The first

is at a point chosen because of the relatively sharp increase of within group error occurring immediately thereafter. Inspection of the membership at this point reveals relatively homogeneous membership with little mixing as compared with the following groups. The second point at which group membership is shown is where there are six groups remaining. The within group error is respectively 264 with 29 groups remaining and 5039 for six groups remaining. It should be remembered that there is no proof that this or any other grouping under this program is valid or more valid on the basis of our single measurement criteria. This technique is offered only as a rough and inexpensive method of estimating the clusters.

It is obvious that the six categories of land use are too broad to adequately describe the data at the spatial resolution used here. What seems a possibly more reasonable approach for the use of higher resolution data of this nature is to describe land uses in terms of mixes of a set of more basic types.

CHAPTER V

CONCLUSION AND SUMMARY

The major finding of this thesis is that there is sufficient information of a quantifiable nature from within the spectral dimension of remote sensor imagery, photographic, to permit the discrimination of land uses in a very broad general classification. There are, however, very definite limitations attached to the practical application and interpretation of such techniques. The resolution and scale aspect is one such factor in application and interpretation. Where scale is smaller and resolution larger, as in ERTS satellite imagery, the resolution element is an integration over a number of smaller targets. There is a physical relation established between systems, with a given resolution and scale, and the nature of the targets and information desired. Therefore it would seem that the desired resolution would be set to maximize the probability of the smallest target completely filling at least one resolution element. In the case of ERTS satellite imagery, the smallest area for which a land use could be ascribed would, depending on the desired probability of establishing spatial location and land use, be considerably in excess of the 1.1 acre resolution given by the system. A similar relationship would hold true at larger scales and smaller resolution. A possible secondary phenomena when the resolution is increased would be an increase in the signatures that could be discriminated. In part, this is suggested by

the hierarchial grouping performed on the basic data. That clustering exercise indicates the possible existance of several clusters within the data taken from test areas. Decrease in the number of signature types with decrease in resolution can be intuitively equated with the generalization that occurs in cartography as map scale decreases.

In terms of spectral signatures, urban areas seem composed of elements that peak in the near infrared and in the blue as registered on CIR film. The probable elements are respectively, vegetation and manmade elements such as pavement and structures. This phenomena has been reported in the literature based on knowledge of the types of targets to be found in urban areas, their spectral reflectivities and the characteristics of color infrared film (37). The selection of variables in the stepwise discriminate program would seem to be in line with the literature. The very broad band nature of the CIR film and microdensitometer spectral filter combination in the feature extraction process prevents the making of a specific definition of the spectral signature from this data.

V.1 SOME POTENTIALS OF AUTOMATIC INTERPRETATION OF REMOTE SENSOR IMAGERY

The utility of any tool must be referenced against a framework of uses, economics, and necessity, as well as its own capabilities. In an era of continuing crises, ecological disasters, food, fuel and raw material shortages, the need for continuing, timely, objective information is a necessity. Remote sensor imagery, especially satellite,

is ideally suited for application to problems on regional, national and global basis.

Since its inception, satellite imagery has found a receptive audience. "Satellite and high altitude remote-sensing coupled with electronic processing are increasingly being used in mineral exploration" (5). Moreover, at the present time, ERTS imagery is considered to be the best cartographic source for mapping at scales of 1:1,000,000 and smaller. And, thematic mapping of major land uses from satellite imagery seems to be one of the major applications now being explored. These are a few examples of the successful applications of satellite imagery to date.

At the resolution now available to the civilian market, minimum of 1.1 acre, it would be difficult to envisage satellite imagery being useful to neighborhood planners. But at the regional, intra urban, level even that imagery now available may prove useful. The CARETS project and the Georgia Atlas, mentioned previously, are two examples. As resolution improves, a possibly more important long range use for planning lies in the application to study the dynamics of urban geography. Available for this purpose through satellite imagery is an objective recording over time of the morphology of every city in North America and, political considerations allowing, the world.

V.2 FUTURE DIRECTIONS

This thesis has approached the field of automatic interpretation of remote sensor imagery of urban areas in the simplest of forms,

a statistical comparison of multispectral data, using the most available imagery, high altitude photographic transparencies. The direct application of its results, simple but successful within their scope, to larger areas is hindered by several factors mentioned previously. Spectral characteristics show variability with a number of factors, sun angle, atmospheric conditions including pollution, and seasonal changes in vegetation. Such factors prevent or hinder a transference of signature from one piece of imagery to another. The difficulties in using spectral data may not be impossible to solve as solutions are being worked on for large scale imagery. The two technical reports by Kenneth R. Piech are indicative of these efforts (39,40). Unfortunately, Piech's efforts have relied on the analysis of shadow effects and this does not appear to be extendable to satellite imagery. As future remote sensing information systems by their nature will tend toward global application involving a continuing flow of imagery, such limitations could considerably reduce the applicability of multispectral data as the major feature dimension. Rather, the need for a relatively stable feature signature suggests the desirability of spatial information. There are a number of efforts presently underway in this area using such techniques as Fourier transforms to provide quantitative assessment of texture and other features in the spatial domain. Spectral information will undoubtedly remain a variable of interest albeit in a supporting role. Possible application of pattern recognition using spectral data to urban studies would seem to lie in the differentiation of urban rural fringe, as an aid in the separation of neighborhood types, and in pollution and ecological surveys in general.

The impending advent of automated interpretation of remote sensor imagery brings with it a new set of considerations and difficulties which may beset the remote sensing community and its users whether researchers or planners. "Planners" is used here in the broadest sense to include any user whose application of information is future directed. As the flow of information increases, the amount of information taken from an image can be expected to drop. This trend has been reported in military applications and can be expected simply because of the degree of redundancy in covering the same areas, every nineteen days in the case of ERTS. In some instances, however, the redundancy is necessary in order to insure at least one image free of cloud cover within some longer period. Moreover redundancy is necessary for the use of the temporal dimension of information.

Automated interpretation, it must be pointed out, relies on the reoccurrence of same or similar patterns. The systems as now envisaged do not take into account unique elements particular to targets of interest. This may be of importance in its use. As mentioned in the introductory chapter, one justification of automated interpretation lies in the ability of computers to handle more dimensions of information and sort through these freeing human interpreters from the routine, though necessary, tasks. In this manner, automated interpretation can supply a continuous monitoring of some phenomena and permit humans to concentrate on the unique elements. However, it is becoming increasingly evident in military circles, and this seems especially applicable to civilian uses, that the major need lies in new "exploitation systems" capable of using the information derivable from this source (53).

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APPENDIX

APPENDIX

STEPWISE DISCRIMINATE ANALYSIS USING THE BMD07M

STATISTICAL PACKAGE

Run 1 (Preprocessed Data)
Number of Variables: 2 - Number of Groups: 6
Number of Cases in each Group: 200
WITHIN GROUPS COVARIANCE MATRIX

VARIABLE	R/G	G/B
R/G	0.02540	
G/B	-0.00928	0.6383

WITHIN GROUPS CORRELATION MATRIX

VARIABLE	R/G	G/B
R/G	1.00	
G/B	-0.23046	1.00

STEP 1 VARIABLE INCLUDED 1 (RED/GREEN)
VARIABLES INCLUDED AND F TO REMOVE - DEGREES OF FREEDOM 5 1194
RED/GREEN 569.0496
VARIABLES NOT INCLUDED AND F TO ENTER - DEGREES OF FREEDOM 5 1193
GREEN/BLUE 39.2786

F MATRIX DEGREES OF FREEDOM 1 1194

	FOREST	AGRIC	RESID 1	RESID 2	COMMER
AGRIC	506.64				
RESID 1	9.84	375.25			
RESID 2	.463	476.46	6.033		
COMMER	382.21	768.96	514.723	409.29	
INDUST	572.48	2156.24	732.448	605.52	19.15

NUMBER OF CASES CLASSIFIED INTO EACH GROUP (maximum likelihood)

GROUP	FOREST	AGRIC	RESID 1	RESID 2	COMMER	INDUST
FOREST	96	9	62	21	12	0
AGRIC	5	174	16	1	2	2
RESID 1	35	8	128	21	2	6
RESID 2	51	34	67	10	28	10
COMMER	22	0	3	1	100	74
INDUST	4	0	0	0	82	114

STEP 2 VARIABLE ENTERED GREEN/BLUE
VARIABLES INCLUDED AND F TO REMOVE
RED/GREEN 602.6126 GREEN/BLUE 39.2784

F MATRIX - DEGREES OF FREEDOM 2 1193

GROUP	FORESI	AGRIC	RESID 1	RESID 2	COMMER
AGRIC	257.44				
RESID 1	41.35	203.11			
RESID 2	3.64	252.15	62.51		
COMMER	207.65	921.80	359.64	210.28	
INDUST	304.24	1117.57	472.16	309.28	9.60

NUMBER OF CLASSES CLASSIFIED INTO GROUP

GROUP	FOREST	AGRIC	RESID 1	RESID 2	COMMER	INDUST
FOREST	69	11	40	67	13	0
AGRIC	12	174	2	9	1	2
RESID 1	19	7	150	18	2	4
RESID 2	37	35	34	57	27	10
COMMER	7	0	3	14	104	72
INDUST	4	0	0	1	81	114

Run 2 Basic (unpreprocessed) Data
Number of Variables: 3 - Number of Groups: 6
Number of Cases in each Group: 200
WITHIN GROUPS COVARIANCE

	VARIABLE		
VARIABLE	RED	GREEN	BLUE
RED	267.85		
GREEN	189.59	373.78	
BLUE	175.90	269.90	374.60

WITHIN GROUPS CORRELATION MATRIX

	VARIABLE		
VARIABLE	RED	GREEN	BLUE
RED	1.00		
GREEN	0.59919	1.00	
BLUE	0.57649	0.74879	1.00

STEP 1 VARIABLE ENTERED 3 (BLUE)
VARIABLES INCLUDED AND F TO REMOVE - DEGREES OF FREEDOM 5 1194
3(BLUE) 481.2595
VARIABLES NOT INCLUDED AND F TO ENTER - DEGREES OF FREEDOM 5 1194
1(RED) 342.6894 2 (GREEN) 59.7080
F MATRIX - DEGREES OF FREEDOM 1 1194

GROUP	FOREST	AGRIC	RESID 1	RESID 2	COMMER
AGRIC	6.46				
RESID 1	610.32	742.89			
RESID 2	40.97	14.89	967.59		
COMMER	164.65	105.38	1407.22	41.64	
INDUST	368.70	277.53	1927.76	163.85	40.875

NUMBER OF CASES CLASSIFIED INTO GROUP

	FOREST	AGRIC	RESID 1	RESID 2	COMMER	INDUST
FOREST	67	39	19	65	10	0
AGRIC	78	61	2	40	5	14
RESID 1	24	5	164	2	4	1
RESID 2	52	19	10	36	46	37
COMMER	14	5	3	16	80	82
INDUST	11	5	3	9	16	156

STEP 2 VARIABLES ENTERED 2 (RED)
VARIABLE INCLUDED AND F TO REMOVE - DEGREES OF FREEDOM 5 1193
1 (RED) 342.0894 3 (BLUE) 481.2595
VARIABLES NOT INCLUDED AND F TO ENTER - DEGREES OF FREEDOM 5 1192
2 (GREEN) 89.8590

F MATRIX DEGREES OF FREEDOM 2 1193

GROUP	FOREST	AGRIC	RESID 1	RESID 2	COMMER
AGRIC	443.09				
RESID 1	307.83	741.87			
RESID 2	45.63	262.06	494.30		
COMMER	116.40	773.15	760.49	138.99	
INDUST	186.27	641.65	973.61	123.54	40.02

NUMBER OF CASES CLASSIFIED INTO GROUP

GROUP	FOREST	AGRIC	RESID 1	RESID 2	COMMER	INDUST
FOREST	107	6	18	33	36	0
AGRIC	4	183	1	10	1	1
RESID 1	23	8	158	5	6	0
RESID 2	25	20	7	92	17	39
COMMER	19	0	1	2	124	54
INDUST	6	0	3	1	48	142

STEP 3 VARIABLES ENTERED 2 (GREEN)
VARIABLES INCLUDED AND F TO REMOVE - DEGREES OF FREEDOM 5 1192
1 (RED) 400.5920 2 (GREEN) 89.8591 3 (RED) 71.1544

F MATRIX DEGREES OF FREEDOM 3 1192

GROUP	FOREST	ACRIC	RESID 1	RESID 2	COMMER
AGRIC	345.17				
RESID 1	206.86	565.05			
RESID 2	30.72	233.06	329.85		
COMMER	125.16	710.29	537.43	132.60	
INDUST	205.40	685.93	706.99	153.58	31.14

	NUMBER OF CASES CLASSIFIED INTO GROUP					
GROUP	FOREST	AGRIC	RESID 1	RESID 2	COMMER	INDUST
FOREST	118	7	18	33	24	0
AGRIC	4	171	1	17	1	6
RESID 1	29	5	157	5	4	0
RESID 2	28	25	7	90	13	37
COMMER	14	0	3	2	129	52
INDUST	5	0	3	0	49	143

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	F VALUE TO ENTER	NUMBER OF VARIABLES INCLUDED
1	3 (BLUE)	458.6047	1
2	1 (RED)	342.0894	2
3	2 (GREEN)	89.8591	3

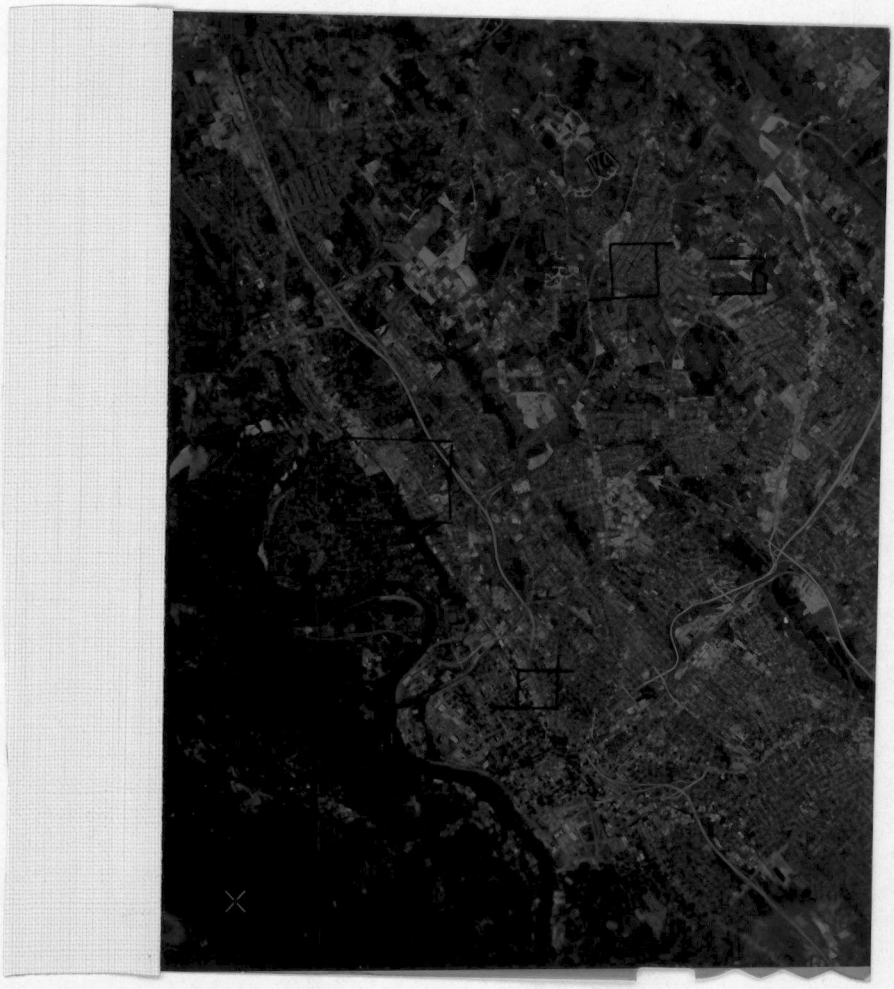

Figure 10. Duplicate of color infrared imagery.

VITA

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In September, 1970, he entered the University of Tennessee, Graduate School of Planning. He received the Master's degree in March, 1975. In September, 1973, he accepted a teaching and research assistantship at the University of Waterloo, Waterloo, Ontario.