October 30, 1974

To the Graduate Council:

I am submitting herewith a thesis written by James P. Rhudy entitled "Use of The University of Tennessee Space Institute Television Densitometer in Remote Sensing Image Analysis." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

F. Shahrokhi, Major Professor

We have read this thesis
and recommend its acceptance:

Walter Frost

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Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

c

USE OF THE UNIVERSITY OF TENNESSEE SPACE INSTITUTE TELEVISION DENSITOMETER IN REMOTE SENSING IMAGE ANALYSIS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

James Phoebus Rhudy

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ABSTRACT

The history of man is characterized by communication in numerous modes. One of these modes is the map, by which man communicates information which has a spatial element. In our present age of severe pressures of population and demand on resources, it is increasingly important to make accurate and timely decisions concerning those resources. The mapping specialists will continue to supply decision-makers with the information necessary for those decisions.

The past history of mapping has seen the development and utilization of many specialized techniques to aid the mapper. Such techniques have always included the field survey as a central activity. Since the development of the aircraft, mapping has been increasingly performed with the aid of aerial photographs. The advent of spacecraft has presented the aerial photographic mapper with yet another platform from which to view his subject, Earth.

The use of the space platform, and the very high altitude aircraft which are also utilized, often reduces the possibility of observing fine detail of Earth features, and force the aerial mapper to abandon his usual photo-interpretive methods in favor of techniques based on color and optical density features of the images. Analysis methods based on such characteristics are also highly suitable for use with automatic data processing equipment.

photography and discusses the need for color and densitometric analysis methods which arises as aerial photographic vehicle altitudes and data flow rates increase. The University of Tennessee Space Institute television densitometer is described, and the use of the instrument in densitometric analysis of aerial photographic transparencies is demonstrated. Results of resolution tests of the instrument are also presented.

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CHAPTER I

INTRODUCTION

Communication between humans has been conducted in many ways; among them are the spoken or written word and various symbolic means. The map is a form of communication designed to convey information, in its spatial context, by means of commonly-understood symbolism. The Egyptians produced maps of administrative subdivisions for governmental convenience. Pacific Island peoples prepared navigation charts for inter-island travel. Wherever government or commerce have required information with a spatial content of significance, maps have been provided. Mapping concepts are discussed in Reference (1).[1]

The information necessary for the production of maps has been gathered by explorers, surveyors, and military observers. Their instruments have included visual inspection, the transit, chain, level, and level rod, the plane table, and, in cases where access to territory to be mapped was difficult, photographic instrumentation. In the years following the development of the airplane, aerial photography assumed importance in mapping and exploration work (2). In more recent years, spacecraft have been used as platforms from which photographic and television-acquired data about

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[1]Numbers in parentheses refer to similarly numbered references in the bibliography.

Earth's surface could be obtained.

When ground survey methods are used for the production of maps, very accurate measurement of distances can be combined with close visual inspection of objects in the field for the preparation of precise and detailed map products. However, such field survey is time-consuming where large areas are to be covered. Aerial photography can be obtained over regions to be mapped, and has proved to be a convenient and economical means of obtaining the mapping data needed. When aerial photographs are used for map-making, a combination of photogrammetry, or careful measurement from the photographs, and photointerpretation, or visual inspection of the photographs to ascertain what physical features such as houses, roads, and bridges, and other objects are present on the ground covered, will suffice to allow detailed maps of the area to be prepared.

When the spacecraft platform is used to acquire information about Earth's surface, the entire surface of the globe is available for surveillance. Moving at orbital velocities, spacecraft can survey the whole surface of Earth on a three-week schedule. Even aircraft survey cannot match this coverage and frequency, and with Earth resource management problems increasing with increased population pressure and industrialization demands, it appears likely that international cooperation in resource management, using space-acquired information, must soon be initiated. Maps of global scope, with major resources and conditions noted, and

with frequent revision accomplished, may soon be communicated among nations as they seek to minimize resource allocation conflicts (3).

One problem with photographic information acquired from orbital and high-altitude aircraft elevations is that much of the detail of Earth's features is lost. Whereas field survey provided immediate object inspection, and conventional low-altitude aerial photography maintained adequate detail for identification of ground features, this detail does not appear in orbital-altitude photography. Such detail is beyond the resolution limits of presently available equipment (4). If an object is viewed from short range, much of its detail will be observable. As the camera is moved away from the object, more area is covered, and the object itself occupies relatively less of the film area. Thus, progressively less of its detail will be detectable. Eventually, with sufficient distance from the object, even the object itself may no longer be resolvable on the film frame. This process may be seen in the case of detection of tree types in a forest. At close range, individual leaves could be photographed and examined to determine their type. In conventional aerial photography, leaf detail has been lost, but the shape of the tree crown, with its orientation of branches, is retained and provides information for identification. At very high altitudes, even the tree crowns appear to blend together, and the principal clues remaining to the observer have to do with the color and

brightness factors of the overall forest area, in color photography, or additionally with its behavior with respect to near infrared radiation, when color-infrared film is used. Thus the acquisition of mapping information by photointerpretation of details of the ground scene gives way to the analysis of color and brightness factors over substantial areas of the film obtained in the mission.

The last factor mentioned above is not entirely a handicap in connection with the mapping of large portions of Earth's surface on a frequent time scale. In order to handle the large rates of data return from such global mapping missions, automatic, computer-assisted image analysis methods are required, and such methods are more easily designed around color or optical density (which is related to brightness) factors in film than around the detailed shapes of objects (5). Rapid scanning of film, with measurement and digital recording of optical density factors, is easily coupled with computer procedures to allow automatic analysis of those factors. If densitometric factors, associated with the color and brightness of objects or regions on the ground, can be reliably related to those characteristics of Earth's surface of interest in resource management, then orbital surveying of Earth's surface can be combined with rapid automatic processing of the data, and computer-generated resource maps can be provided on a timely basis.

The University of Tennessee Space Institute (UTSI) is engaged in the study of Earth resource remote sensing, which

encompasses the modern practice of aerial photography and photogrammetry together with those aspects introduced by the space platform and automated data analysis. The UTSI Remote Sensing Laboratory operates a television scanning densitometer which is designed to allow measurement and recording of the optical density factors referred to above. It is the purpose of this study to discuss briefly some examples of recent aerial photography, to illustrate the need for color and optical density-based analysis which arises in high-altitude aerial surveying, and to demonstrate the use of the UTSI television scanning densitometer, operating in the digital mode, in the analysis of remote sensing imagery by optical densitometry. Resolution of the UTSI instrument will also be discussed.

CHAPTER II

EXAMPLES OF RECENT AERIAL PHOTOGRAPHY

Aerial photography has been used for many purposes, including that of pictorial illustration from the aerial perspective, as shown in Figure 1, as well as for mapping purposes. Figure 1 shows an oblique view of The University of Tennessee Space Institute. The oblique view shown here is not commonly used for mapping purposes. A vertically photographed view, such as is shown in Figure 2, is used for mapping. This photograph is one of a vertically-photographed series taken with approximately 60 percent overlap between adjacent photographs along the flight line. Each photograph could be used for mapping the urban area. Overlapping photograph pairs can be used with a stereoscopic viewing instrument to see the scene in three-dimensional perspective, and to measure heights of the objects observed. Figure 2 was taken from an altitude of 3,000 feet, above Rockwood, Tennessee.

The same area of Tennessee is shown, as photographed from 60,000 foot altitude, in Figure 3. Again a series of photographs was taken with 60 percent overlap along the flight line, and when adjacent photographs are viewed through the stereoscope, much information can be obtained concerning relief of geologic features. In particular, the ridge which has guided city development is clearly observable

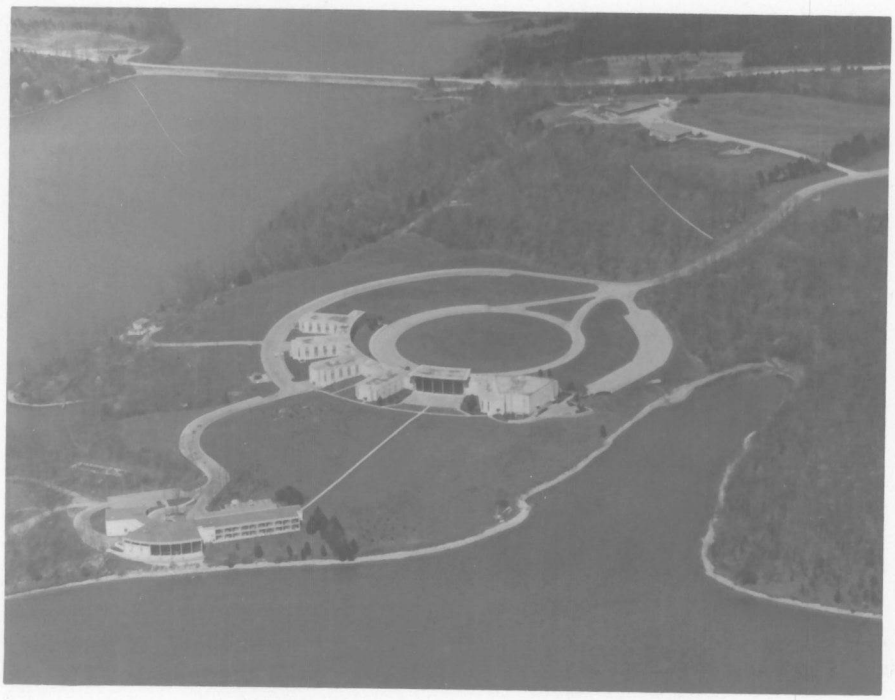


Figure 1. Oblique aerial view of The University of Tennessee Space Institute.

Source: The University of Tennessee Space Institute, Tullahoma, Tennessee.

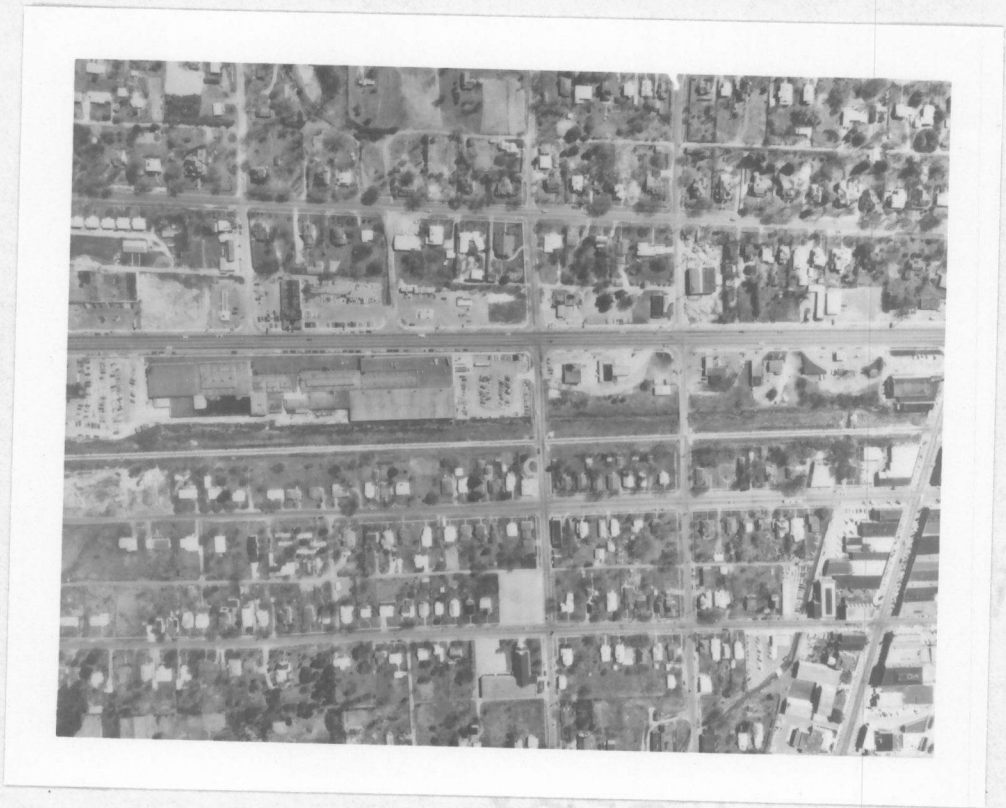


Figure 2. Vertical aerial photograph of Rockwood, Tennessee taken from 3,000 foot altitude.

Source: The Tennessee Valley Authority Maps and Surveys Branch, Chattanooga, Tennessee.



Figure 3. Vertical aerial photograph of Rockwood, Tennessee taken from 60,000 foot altitude.

Source: The National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama.

in the stereoscopic view. Topographic maps of the area may be generated with information obtained photogrammetrically from these photographs.

Two additional uses of aerial photography which are related to the management of coal resources are shown in Figures 4 and 5. Figure 4 is one of a stereo pair of photographs of a coal supply at a Tennessee Valley Authority (TVA) station. The annual inventory of coal stocks is made by using photogrammetric techniques to measure the volume of coal in each supply pile. In Figure 5 a strip mine region is shown. The area noted appears, under stereoscopic viewing, to have been subjected to undercutting, whereby coal is extracted from under the hillside.

The variety of uses to which such aerial photographs may be put is suggested by the following example. It is known that road vehicle traffic generates noise, and that roadside buildings tend to shield nearby residential areas from that noise, according to their height and location. The heights of the buildings along the main street in Figure 2 may be measured with the photogrammetric parallax bar and stereoscope, and their locations may be scaled off the photograph. This information contributes toward production of a residential noise level map for the city.

Forestry and crop survey applications of aerial photography are illustrated in Figures 6, 7, and 8, which show wooded areas and croplands from various altitudes. Figure 6 is a low-level photograph in which tree crown



Figure 4. Vertical aerial photograph of coal supply at a Tennessee Valley Authority station.

Source: The Tennessee Valley Authority Maps and Surveys Branch, Chattanooga, Tennessee.



Figure 5. Vertical aerial photograph of strip mine region.

Source: The Tennessee Valley Authority Maps and Surveys Branch, Chattanooga, Tennessee.



Figure 6. Low altitude aerial photograph of wooded area.

Source: The Tennessee Valley Authority Maps and Surveys Branch, Chattanooga, Tennessee.

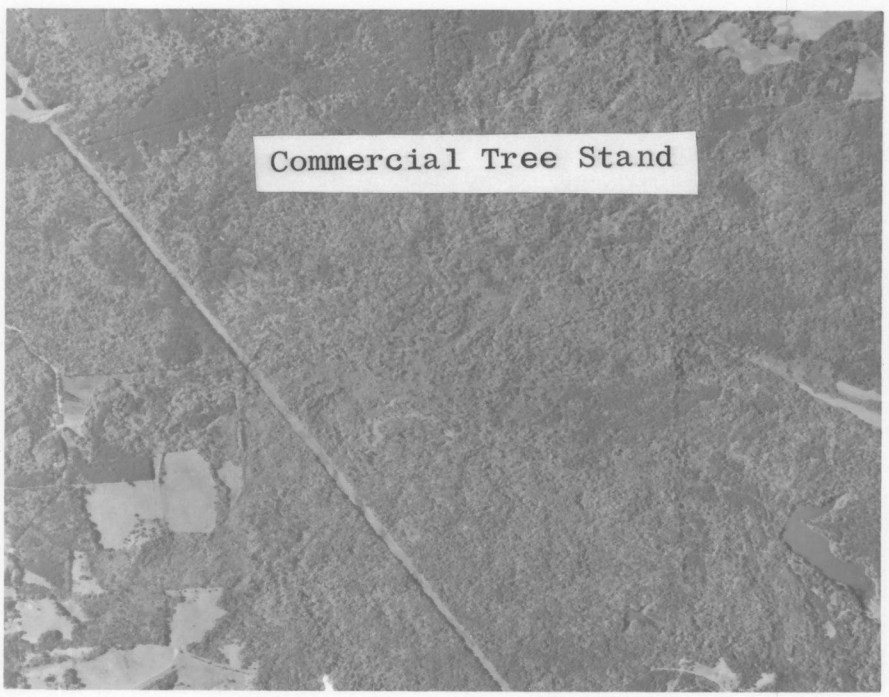


Figure 7. Medium altitude aerial photograph of wooded area.

Source: The Tennessee Valley Authority Maps and Surveys Branch, Chattanooga, Tennessee.

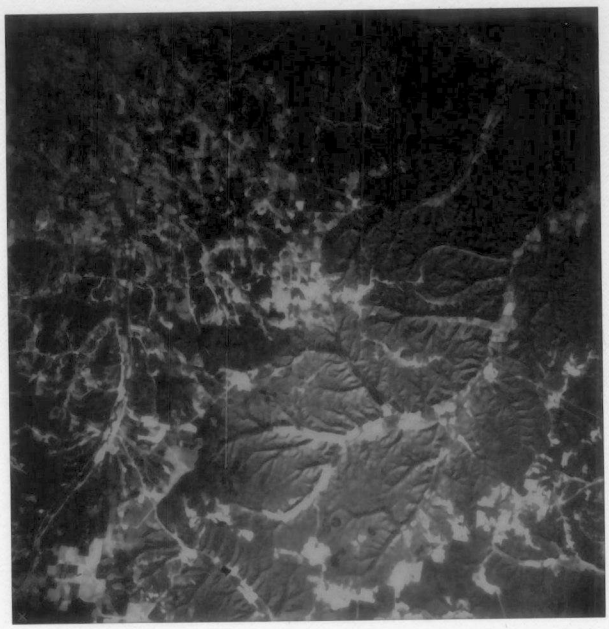


Figure 8. High-altitude color-infrared aerial photograph of wooded and cropland areas.

Source: The National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama.

shapes are easily seen. Tree types may be recognized with the help of the abundant detail available in such low altitude photography.

In Figure 7, taken from about 10,000 feet, the tree crown shapes are no longer clearly detectable. If the tree types were known, tree counts might be made by estimating the number of roughly separable dots in the overall texture of the wooded areas. Some auxiliary clues to tree type may be found for the area marked "Commercial Tree Stand." Here the texture is uniform, indicating uniform tree height, and thus that the field was planted all at one time. There also appear to be access roads through the stand. The forester's knowledge of which tree types are commercially managed in the manner indicated could possibly lead to an identification of this stand as pine. However, the identification would then be made on the basis of auxiliary clues rather than on examination of tree shape details, because the effect of altitude has been to eliminate such detail. In Figure 8, which is a print from a color-infrared photograph taken from 60,000 foot altitude, individual tree detail is definitely lost, and each of the various areas of forest and cropland is distinguished by color rather than by detail of its features. The use of color-infrared film has, however, allowed interpretation of many ground features on the basis of their distinct colors. This photograph was taken in November, and evergreen tree stands appear red in this type of film, while deciduous trees, whose leaves have turned

yellow or red, appear green. Various field conditions produce farmland colors of grey or light red. The grey fields are bare soil, not yet planted or with very small, early plant growth. The light red fields probably have an early growth of small grains or permanent pasture.

It may be noted that the interpretation of the high-altitude photograph for forest type and crop plantings is based on color, rather than on object detail, whereas the information on building height obtainable from stereo pairs similar to Figure 2, page 8, relies entirely on object detail. If a precise, tree-by-tree map of a forest stand were required, then low-altitude photographs such as Figure 6, page 13, would be necessary. For overall, large-area surveys of forest cover or crop plantings, high-altitude photographs such as Figure 8, page 15, are suitable, and orbital-altitude images such as Figure 9, taken by the National Aeronautics and Space Administration (NASA) Earth Resources Technology Satellite (ERTS), are useful. In the worldwide search for resources of food and minerals, such imagery will prove of inestimable worth, particularly when rapid, automatic scanning and analysis of the imagery is performed, as discussed in Chapter III.

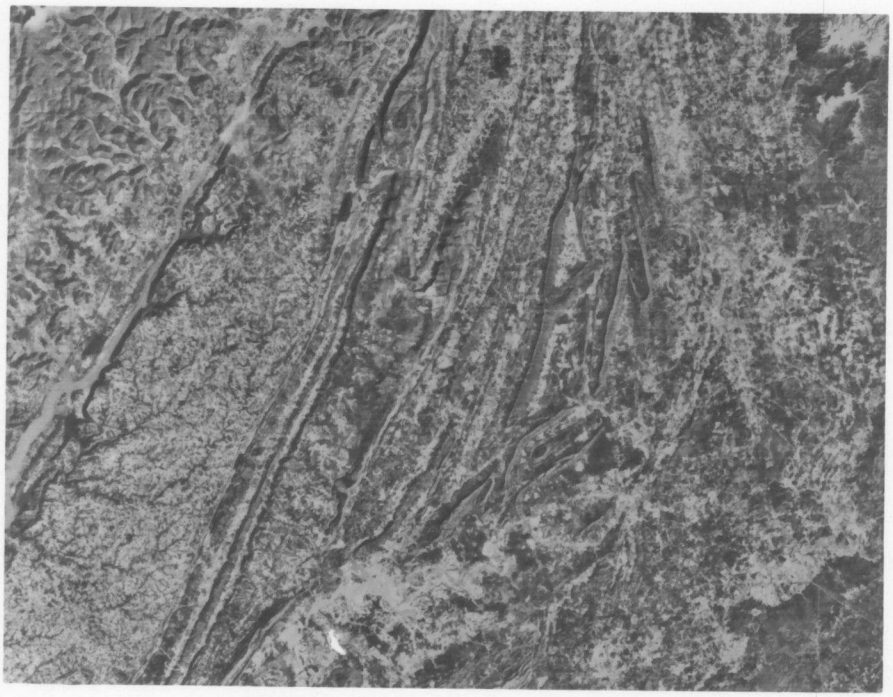


Figure 9. Earth Resources Technology Satellite image of Middle Tennessee.

Source: The National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama.

CHAPTER III

NEED FOR DENSITOMETRIC ANALYSIS IN PHOTOGRAPHIC REMOTE SENSING

The loss of detail which accompanies the use of present, commonly-used equipment at very high altitudes has been shown in Figure 8, page 15, and Figure 9. This loss of object detail creates the need for interpretation methods based on scene color and brightness factors. The use of special films, such as color-infrared, can aid in such analysis, as is shown in Figure 8 in which certain of the important elements appear dark red, while others are light red, grey, or green. Where knowledge of the significance of the various colors, in their relation to various vegetative covers, exists, interpretation and mapping of large forest and cropland areas is possible.

Interpretation of aerial photographs by color and film optical density, which is related to scene brightness, has another important advantage over interpretation methods based on details of shape, in that the color and density characteristics of film lend themselves readily to automatic reading and recording methods, which are capable of scanning and recording scene element characteristics at modern computer speeds. The color-infrared transparency image of Figure 8 may be quickly scanned, and hundreds of point readings of optical light transmission through the film may

be read and recorded for each field, in lengths of time on the order of seconds. These recorded readings may then be automatically interpreted by computer, and the results of forest type classification and cropland use identification may be printed out in thematic map form. The savings of time over manual methods is considerable, and is particularly significant where large areal coverage and repetitive surveys are contemplated, as is the case with global spacecraft and high-altitude aircraft survey missions (6). A discussion of the time factor in remote sensing data analysis is presented in Reference (7), whose author is engaged in development of an automatic method to take advantage of repetitive, large-area ERTS coverage for the production of timely, accurate crop estimates.

Color and density analysis of imagery is useful in fields other than forestry and agriculture. In water pollution studies, suspended sediments are detected primarily in terms of color differences in the polluted water body, and oil slicks are examined through their color and brightness differences from the surrounding water surface. In air pollution studies, stack plume dispersion is analyzed by measurement of the optical density variations produced on color photographs by the pollutant plume. The manner in which color and color-infrared films record the colors and brightnesses of ground scenes to be interpreted, and the operating principles of the UTSI television densitometer which is used to scan and record data from those images, are

discussed in the following chapters. The use of densitometric measurements to classify scene elements is illustrated and an application of the method to some of the crop and forest areas (Figure 8, page 15) is presented. The application of the television scanning densitometer to the field of remote sensing is discussed further in Reference (8), which contains references to applications in such areas as water and air pollution.

CHAPTER IV

THE UNIVERSITY OF TENNESSEE SPACE INSTITUTE TELEVISION DENSITOMETER

The UTSI television densitometer system (Figure 10) is composed of an input television camera which scans the image to be analyzed, and of various signal processing and display components. The display components on the analyzer include a digital meter which reads out a value proportional to the light coming through the film at a given point. There are also a cathode ray tube oscilloscope (XY Display Monitor) which presents essentially a graph of values proportional to the light transmission through the film, and a color television set (TV Monitor) modified to allow representation of the relative optical densities of the image in color-coded form.

I. TELEVISION CAMERA

The television input camera is a standard black and white Vidicon tube with associated circuitry. The key element is the Vidicon tube itself which operates, with reference to the schematic sketch of Figure 11, as follows:

Images of transparencies illuminated by a light table are focussed by optical lenses onto the sensitive photoconductive layer within the Vidicon tube. The scanning electron beam seeks to charge the scanned inner surface of

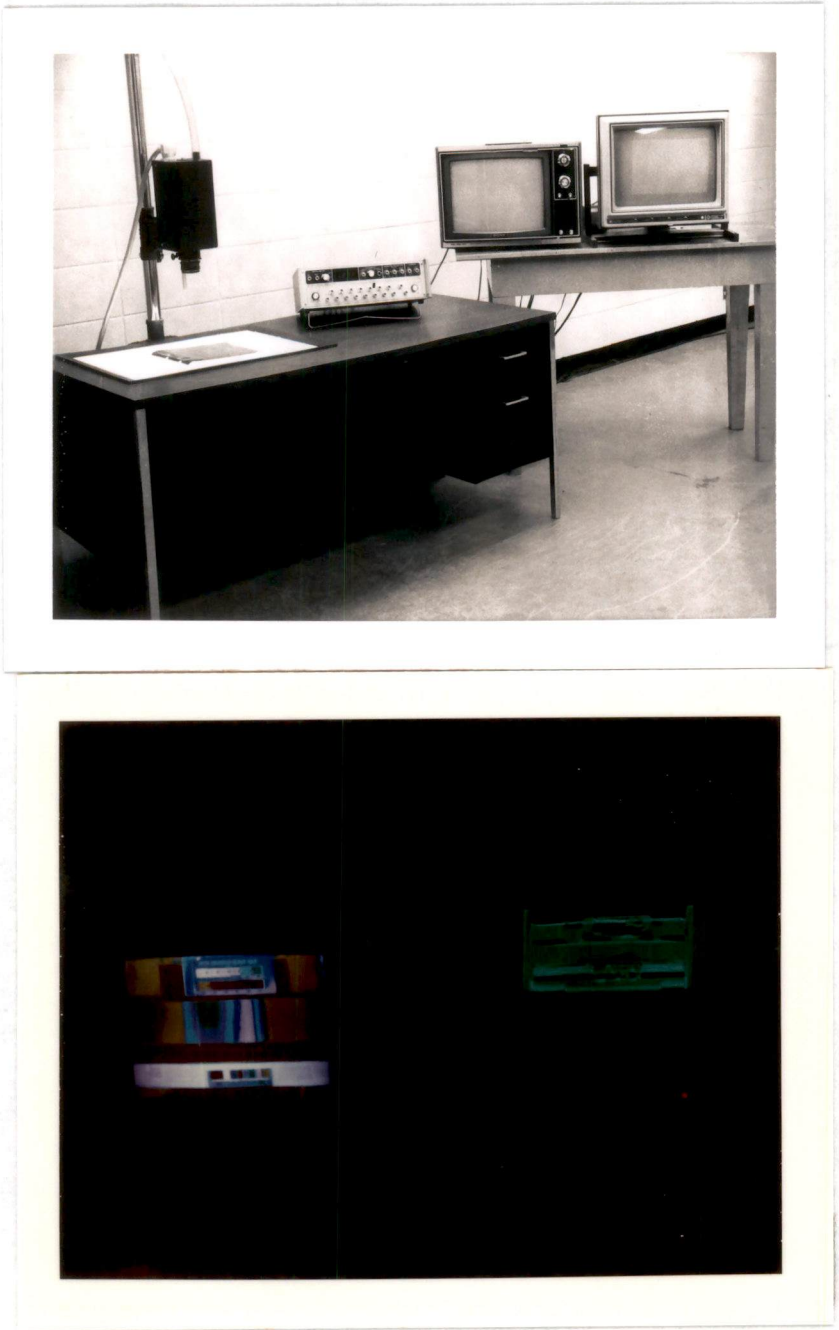


Figure 10. The University of Tennessee Space Institute television densitometer system.

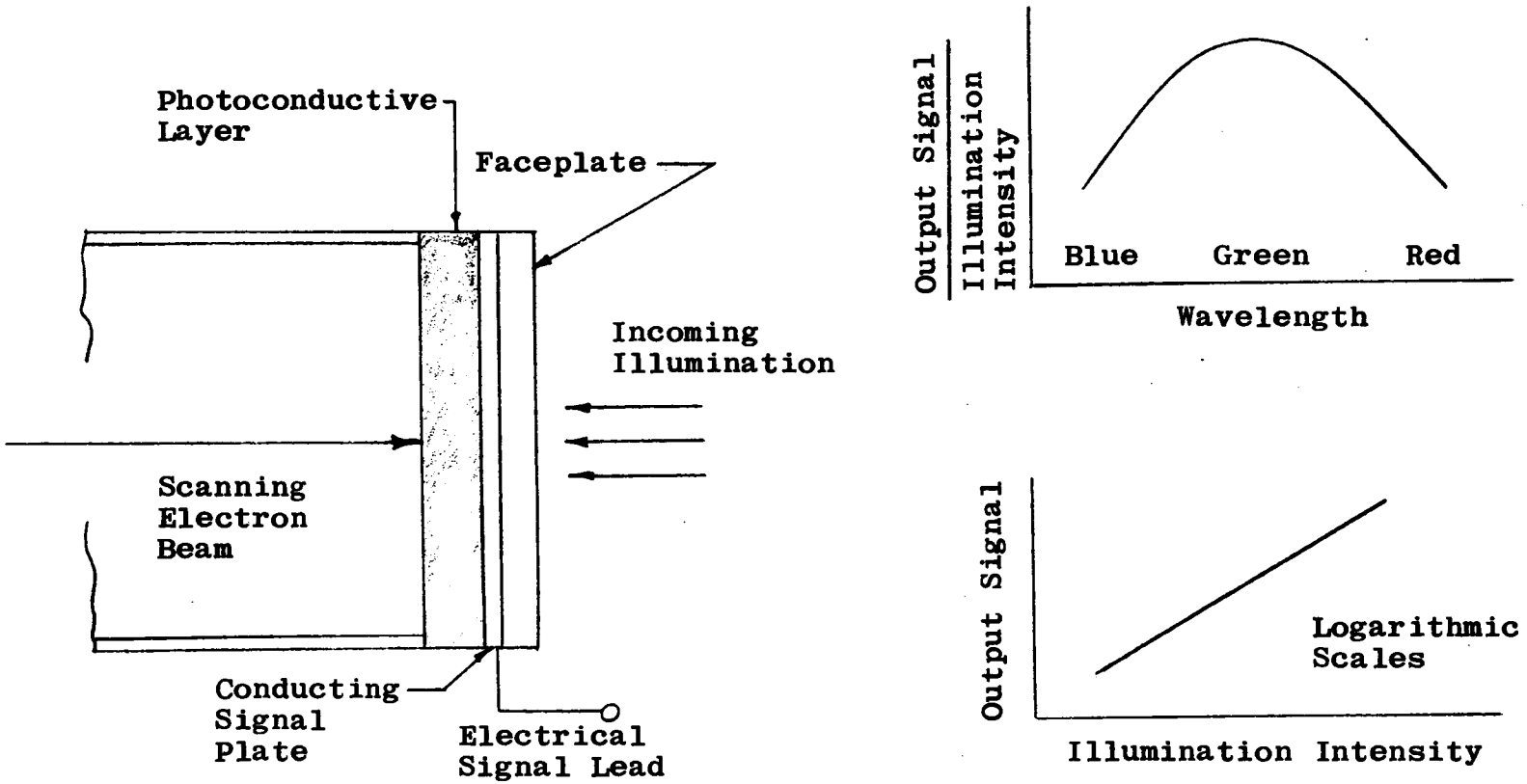


Figure 11. Schematic illustration of television camera Vidicon tube.

the photoconductive layer, point-by-point, with electrons. Since the photoconductive layer conducts electrons from each point of the inner surface into the bulk of the layer in amount proportional to the amount of light striking each point of the layer (hence the term photoconductive), the scanning beam is able to deposit more electrons on the inner surface at those highly illuminated points where electrons have been conducted away rapidly from the surface than it can at those points where low illumination has left the photoconductive layer only slightly able to conduct electrons away from the inner surface. The deposition of electrons at points on the layer inner surface induces a corresponding flow of electrons on the signal layer side of the photoconductive layer, through the capacitance effect. This signal layer is connected to the output signal lead, so that when the electron deposition rate to the inner scanned surface spots is great, there is a large current flow in the signal lead. Thus the manner in which the Vidicon tube converts illumination values from transparent images into electrical signals is by generation of an output signal which increases in strength with increased brightness of the image points. The relationship between output signal current and incoming illumination is logarithmic in nature, as illustrated in the sketch on Figure 11. The Vidicon tube is not equally sensitive to light of all wavelengths, as is illustrated in the diagram of sensitivity, as it varies with wavelength of incoming illumination. Optical filtering

can be used to compensate for this characteristic.

II. ANALYZER

The Vidicon camera operates in a scanning mode, with the electron beam sweeping over the inner surface of the photoconductive layer generating an output signal which corresponds in strength with the brightness of the image points focussed on the layer. The scanning rate is 30 complete image sweeps, or frames, per second. The output voltage of the scanning camera signal is digitized for reading on the analyzer digital meter. This is accomplished by an electrical circuit, using solid-state logic devices, in the following way:

The television camera output voltage is connected to a comparator device, which compares its value to the value of a reference voltage also connected to the comparator. If the television output voltage is different from the reference voltage, the comparator turns on a reference voltage stepping device, which automatically changes the reference voltage in small increments until the reference and television signal voltages have the same value. The comparator then stops the stepping device and a readout circuit from the stepping device is connected to the digital meter. The stepping device, operating on an incremental-voltage basis, is a digital device, with each step level having a digital representation. It is this digital value which is transmitted to the digital meter for readout. The time for

sequencing the stepping device is on the order of nanoseconds, which allows close tracking of the television output signal value.

The measured value of voltage varies with the amount of light coming through a transparency to the Vidicon tube. This amount of light depends on the light output of the light table on which the transparency is placed and on the optical density of the transparency itself. In normal operation, the digital meter is set to read zero when the lens cap is on the camera, blocking out all light. There is a variable scale factor adjustment to the digital meter which allows it to be set to read any convenient number from 0 to 2,000, to correspond to the signal produced by a chosen reference point on the transparency being scanned or on a densitometric standard. When the meter is set to read a number, such as 1,000, when a reference point on a transparency is being observed, the reading is only relative to that transparency and not to a standard such as a calibrated densitometric wedge or grey scale. All references to measurements made with the television densitometer in work reported herein are to relative light transmission, and the instrument meter reading and a description of the reference point on the transparency are given. The analyzer is also capable of generating a horizontal and vertical cursor line pair onto the monitor screens. The intersection point of these movable cursors determines the image point whose output signal value is digitized and read on the digital meter.

III. XY DISPLAY MONITOR

The output signal of the television camera is used to drive the vertical spot-deflection circuit of a cathode ray tube. As the output signal increases, the spot is deflected upward from the reference level. The cathode ray tube (CRT) beam, without camera signals imposed, is forced to follow the Vidicon tube beam scanning pattern. Vertical deflections of the CRT beam, caused by variations in camera output signal, cause deviations from the normal XY pattern of scanlines in proportion to scene brightness variations, and thus present a pseudo-three dimensional image representative of original image brightness variations. This capability may be used to analyze images for overall brightness, or light transmission, variations.

IV. TV MONITOR

The television monitor is a standard color television set modified to allow the color guns red, blue, and green to be driven by the analyzer-processed camera signal rather than by color television camera signals. Solid-state switching circuitry receives the single incoming television output signal and assigns one of eight colors to each of eight bands of voltage value. The television set scanning pattern is synchronized to the Vidicon tube scanning pattern, as in normal operation, but the color gun outputs are determined by the camera voltage output level. Thus a

television camera output voltage range from 0 to 0.8 volts could be subdivided into eight levels, as from 0 to 0.1, 0.1 to 0.2 volts, and each voltage band can be assigned a color such as red, cyan, orange, or purple. When the output voltage corresponding to a point on the image being scanned is within a certain range, the color corresponding to that voltage range will be displayed on the monitor screen, rather than a color the image normally would display. Thus a reproduction of the original scene, with colors corresponding directly to image brightness levels, is displayed on the TV monitor screen. This capability is useful for rapid analysis of individual image brightness, or optical transparency, variations, and is referred to as density slicing by color coding.

The UTSI television densitometer was used in the demonstration applications reported in this work in the digital mode only. Readings of relative light transmission through color and color-infrared transparencies were made by manually reading the analyzer digital meter and writing down the value. The principles of positive transparency reversal color films, which were used in the demonstration are discussed next.

V. POSITIVE TRANSPARENCY REVERSAL COLOR FILM PRINCIPLES

The relationship of the color and density of a photographic transparency to the color and brightness of a ground

scene is very complex and has been the subject of detailed study for many years. The technical fields of color film chemistry, densitometry, sensitometry, and tone reproduction are concerned with these matters, and some aspects of color photography may perhaps never be resolved because they depend on the psychological response of the observer. For purposes of aerial photographic work, the exposure of the film is selected to produce a finished product which, although it may not be natural in color and tone, will however allow accurate interpretation of ground scenes.

The photographic density which results from exposure of color film is a combination of the densities of three film layers, each of which contributes, in a color-subtractive process to the final color which is transmitted to the observer (9). Thus in the usual color reversal transparency film there will be a yellow layer, a cyan layer, and a magenta layer, each of which is a filter for certain wavelengths. The fully developed yellow film layer will stop blue and transmit red and green. The completely developed cyan layer will stop red and transmit blue and green, and the developed magenta layer will stop green and transmit red and blue. Since ground scene colors may be represented by various combinations of red, blue, and green light, it may be seen that by varying the density of each film layer, thus varying the amounts of red, blue, and green light transmitted, the ground scene color may be reproduced in the photographic transparency. Figure 12 illustrates the

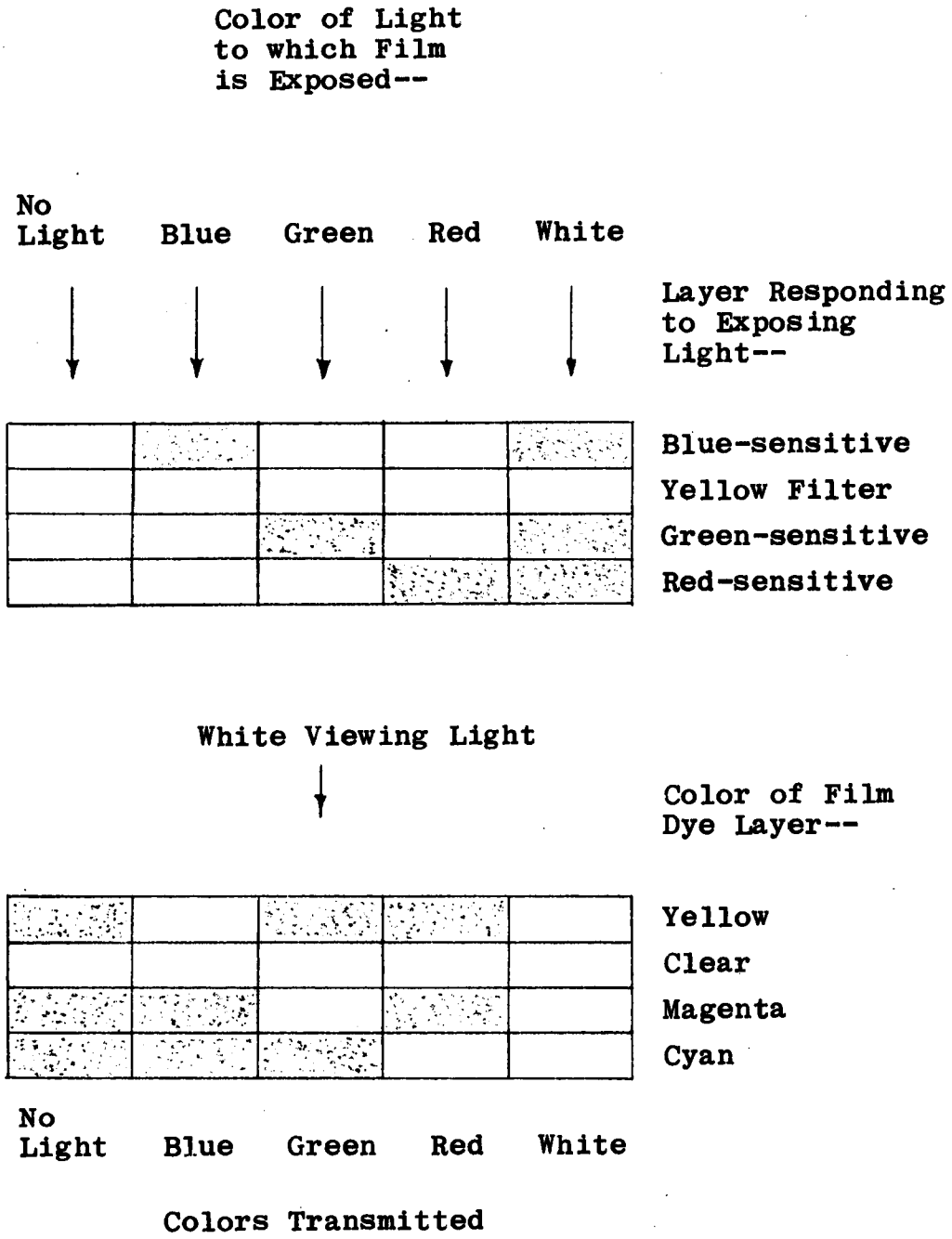


Figure 12. Schematic illustration of positive transparency reversal color film principles.

formation of the finished color transparency after exposure to ground scene illumination.

As the film is initially manufactured and supplied, it is composed of four layers which are effective in the color formation process. The three layers marked as sensitive to blue, green, and red light are gelatin layers with silver halide grains in suspension throughout the layers. The silver halide grains contribute light-sensitivity to the overall process. The manner in which the layers are rendered sensitive to particular colors is by use of sensitive dyes. The silver halide grains are primarily sensitive to blue, violet, and ultraviolet light, rather than to light more toward the greens and reds. H. W. Vogel of Berlin discovered in 1873 that certain organic dyes when placed in emulsion with the silver halide would give photographic sensitivity to the emulsion in the absorption region characteristic of the dyes used. By a process as yet not fully understood, these dyes, when adsorbed onto a silver halide grain, are capable of absorbing light energy and transferring that energy to the grain, which otherwise would not respond to light in that frequency. In multilayer color film, the sensitizing dyes are selected to render the silver halide grains sensitive to green and red light. The blue-sensitive layer would be sensitive to blue light by virtue of the silver halide grains alone. This fact makes necessary the use of the yellow filter layer shown just under the blue-sensitive layer in the sketch. Since the red and

green-sensitive layers retain the blue sensitivity of the silver halide grains, it is necessary to block out blue light from the lower two layers in order to confine their sensitivity to red and green alone. The ability to sensitize layers of the film to various spectral regions extends to the near-infrared frequencies. Layer sensitivities of color-IR film compare to those of ordinary color film as follows (Table I):

TABLE I

LAYER SENSITIVITIES OF COLOR-INFRARED FILM COMPARED TO ORDINARY COLOR FILM

Films	Exposing Light Color	Dye Layers Produced	Resulting Light Color Transmitted
Ordinary color film	None	Magenta, cyan, yellow	None
	Blue	Magenta, cyan	Blue
	Red	Magenta, yellow	Red
	Green	Yellow, cyan	Green
	Near-infrared	Not sensitive	
Color-IR (with blue subtracting filter on camera lens)	Blue	Magenta, yellow, cyan	None
	Red	Yellow, cyan	Green
	Green	Magenta, cyan	Blue
	Near-infrared	Magenta, yellow	Red

Thus in color-infrared transparencies, objects reflecting large amounts of near-infrared radiation will appear red. Other objects appear with colors shifted from their true values, leading to the description of color-IR film as a false-color film.

In the processing of color film, those layers which were exposed to light of red, blue, and green color are bleached out in proportion to the degree of exposure they have received, and those layers which were not so exposed retain their unexposed halide grains. These grains and associated dyes form the basis for the production of the dyes magenta, cyan, and yellow in layers which were sensitive to green, red, and blue respectively. Thus a section of film which was exposed to red light would have its red-sensitive layer bleached to a clear condition. The other two layers, unaffected by the red light, would have produced in them magenta and yellow dyes, which together allow the red component of white light to pass through. The process involves not the production of a single layer of the color to which it was originally sensitized, but to two layers which together pass the desired color.

Scene brightness is represented in the final transparency by variations in density of the dyed layers. The density of the dyes in the layers decreases with increasing amount of light from the viewed object. An object reflecting only red light into the camera will be represented by red light passed by the yellow and magenta film layers. If the object is very bright, the cyan, originally red-sensitive layer, will be washed out and all the red component of light presented to the transparency will come through. If the object were less bright, the cyan layer will be dyed to dye-density inversely proportional to the brightness of the red

light to which it was exposed. This cyan layer will then reduce the amount of red light coming through the magenta and yellow layers in proportion to its density. Thus the subtractive process of the three layers is capable of representing both the colors and the brightnesses of the original scene, within the limits of the photo-chemical processes of color photography. The processes by which aerial color or color-infrared photography are analyzed by densitometers make use of the fact that the original ground scene is being represented by essentially a superposition of three filtering layers of varying filter density. The transmissivity of points on the film may be measured directly, or additional colored filters may be superimposed over the transparency where this is helpful in discriminating ground scene elements.

CHAPTER V

DEMONSTRATION OF USE OF THE UNIVERSITY OF TENNESSEE SPACE INSTITUTE DENSITOMETER IN DENSITOMETRIC IMAGE ANALYSIS

I. DENSITOMETRIC MEASUREMENTS ON A SAMPLE TRANSPARENCY

The UTSI television densitometer was used to make sample measurements on a transparency photograph of Kodak Color Control Chips (Figure 13). Measurements of relative light transmission were made on the chips marked Violet, Green, Red, Magenta, Cyan, Yellow, and White. Measurements were taken without filter, and with red and blue filter sheets superimposed on the transparency, in the following manner:

The transparency was placed over the center portion of the light table in such a location that the white chip was centrally located on the television monitor screen. This central point may be located by use of two mutually perpendicular intersecting cursor lines which are generated on the monitor screen by the analyzer component. The television camera was positioned with its lens ring--lower edge--1.9 inches from the light table surface, which afforded sufficient magnification of the individual color chips that 20 separate point values of relative light



Figure 13. Color print sample positive color transparency.

Source: The University of Tennessee Space Institute, Tullahoma, Tennessee.

transmission could be obtained from each chip without overlapping or approaching too close to the chip edge. The analyzer cursor setting, which determines the point on the camera scan which is digitized, was kept fixed and the transparency was moved on the light table to generate the series of measured values. The digital meter was calibrated to read zero when the camera lens cap was in place (zero light transmission) and to read 750 when the white chip was centered on the cursor intersection point, without filter, and with the camera lens set at f/3.5. The tabulated data are presented in Table II.

II. APPLICATION OF DENSITOMETRIC MEASUREMENTS TO NUMERICAL COLOR CHIP CLASSIFICATION

The purpose of densitometric analysis of images is to allow numerical classification of the objects observed in the image, on the basis of densitometric measurements alone. Normally a large number of similar photographs will be analyzed and the densitometric values digitized. A digital computer will assign each measured value as belonging to one or another image object class. The computer must be programmed with some numerical test by which to make its decisions. The simplest test which may be applied to classify data is a value range test. Such a test was applied to the non-filtered data of Table II.

Figure 14 shows the histograms of the measured data. If a measured value of relative light transmission, x, is

TABLE II

MEASUREMENTS OF RELATIVE LIGHT TRANSMISSION FROM A SAMPLE PHOTOGRAPHIC TRANSPARENCY OF COLOR CONTROL CHIPS

Type of Filter Used	Chip Colors						
	White	Cyan	Violet	Magenta	Red	Yellow	Green
No filter	753	370	79	276	201	497	129
	764	354	74	284	204	496	136
	765	352	71	290	205	504	139
	764	367	72	287	204	500	132
	753	356	71	284	204	507	136
	766	364	74	282	206	502	127
	771	367	77	289	204	513	127
	762	354	68	292	201	505	132
	766	362	68	281	204	498	130
	767	366	71	293	203	501	133
	768	362	74	287	205	497	138
	759	370	81	293	208	508	130
	751	370	79	276	208	509	133
	746	346	80	274	202	499	128
	757	353	67	284	210	493	120
	764	362	64	293	199	493	128
	768	366	65	296	201	494	122
	758	349	71	272	195	491	119
	750	352	69	274	208	497	125
	759	362	65	277	201	502	123
Mean values	761	360	72	284	204	500	129
Standard deviations	7.0	7.6	5.2	7.5	3.5	6.0	5.7
Red filter	253			164	167	239	
	251			166	169	234	
	251			169	164	238	
	251			168	166	238	
	255			166	164	240	
	254			167	163	242	
	255			164	168	242	
	256			167	167	244	
	253			166	170	240	
	257			171	168	237	
	254			167	164	238	
	261			166	164	238	
	260			164	164	243	

TABLE II (continued)

Type of Filter Used	Chip Colors						
	White	Cyan	Violet	Magenta	Red	Yellow	Green
	257			163	168	241	
	261			165	166	239	
	262			172	167	237	
	261			168	162	238	
	260			167	166	242	
	257			169	165	242	
	254			169	165	243	
Mean values	256			167	166	240	
Standard deviations	3.6			2.5	2.1	2.6	
Blue filter	484			128	41	246	
	485			127	42	242	
	486			136	41	246	
	484			129	39	240	
	487			124	41	240	
	486			132	40	244	
	488			127	42	238	
	483			130	42	247	
	478			126	42	244	
	481			121	44	243	
	482			130	43	239	
	487			128	43	239	
	481			125	43	241	
	485			133	44	241	
	489			132	44	247	
	490			131	44	247	
	483			128	43	251	
	483			133	45	249	
	491			132	46	247	
	490			131	47	244	
Mean values	485			130	43	244	
Standard deviations	3.4			3.0	2.0	3.7	

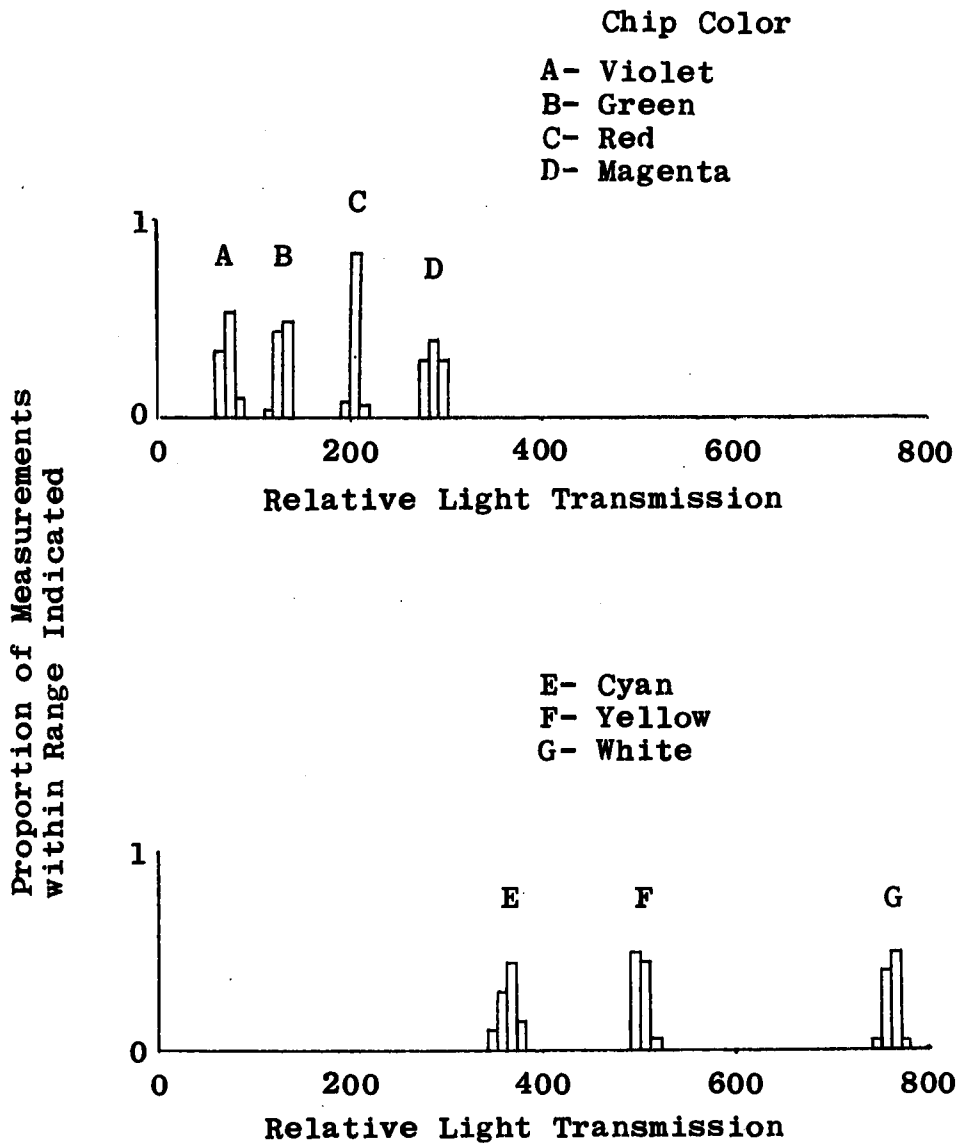


Figure 14. Histograms of relative light transmission measurements from sample positive color transparency color control chips.

less than 100, the point at which that measurement was taken was located in the violet chip. Similarly, if the value of x is between 100 and 150, the point was taken from the green chip. Value ranges by which each measured value of x can be assigned to a color chip are as follows:

Assign point to color--	If--
Violet	$x < 100$
Green	$100 < x < 150$
Red	$150 < x < 250$
Magenta	$250 < x < 320$
Cyan	$320 < x < 400$
Yellow	$450 < x < 550$
White	$700 < x < 800$

An estimate of the confidence level of the above point classifications can be obtained by assuming a normal distribution of the data, and comparing the width of the classification ranges with the values of mean plus or minus two standard deviations. This width, mean $\pm 2\sigma$, will contain approximately 95 percent of the data points of that data set. The classification ranges are in each case wider than this value, and thus may be estimated to contain greater than 95 percent of the data points, correctly classified.

In Figure 15, a comparison is shown between two different types of classification problem which arise in the use of densitometric data. For examining these problems, values of relative light transmission measured with the red

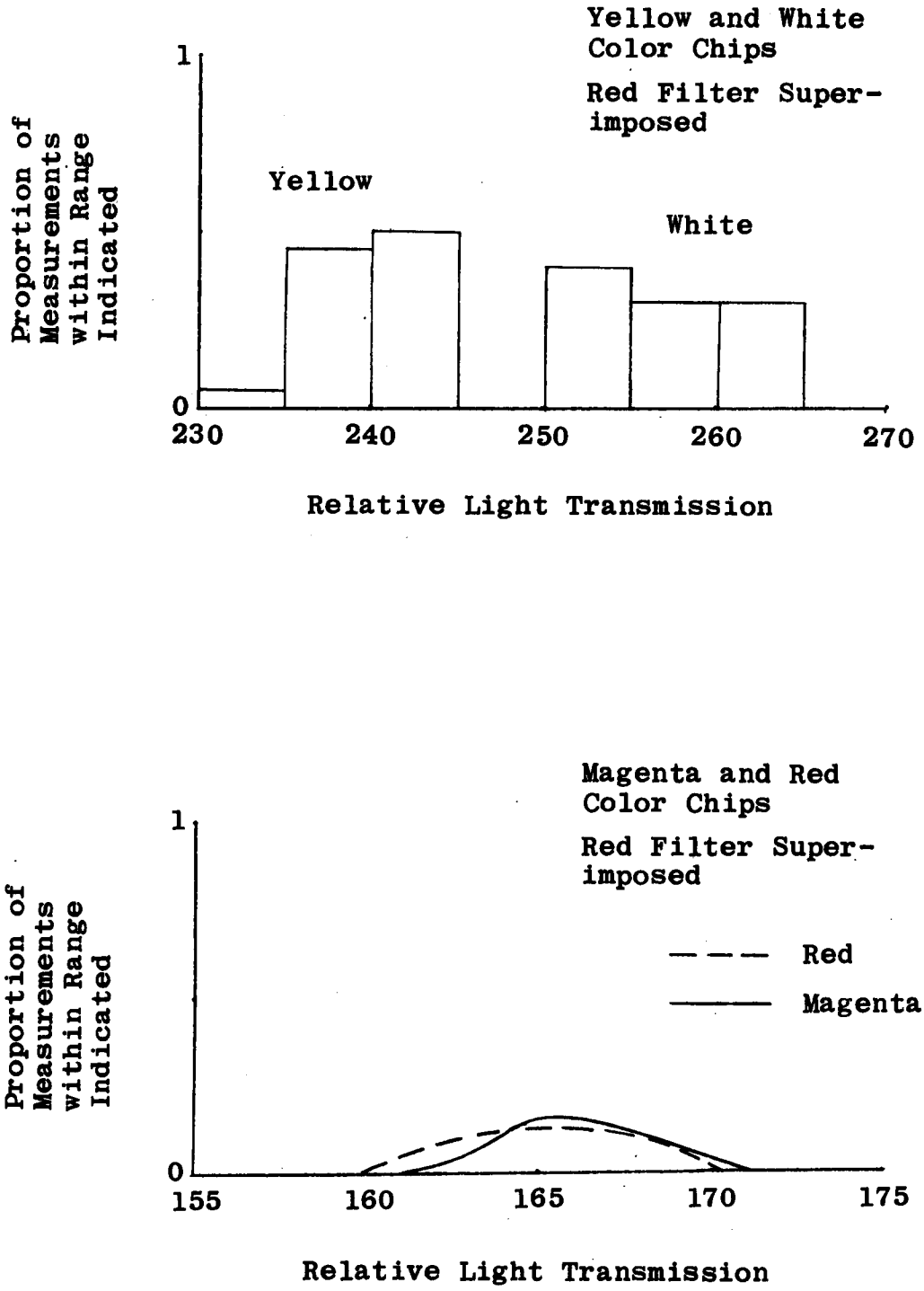


Figure 15. Comparison of two types of classification problems arising in use of densitometric data for numerical classification of image elements.

filter placed over the transparency are used. These measurements are denoted x_R. Points from the yellow and white chips may still be classified by a value range test, with the separating values $x_R < 246$ for points to be classified yellow and $x_R > 246$ for white points. The test value is more than two standard deviations away from each mean value, so that the 95 percent confidence level is maintained. For the magenta and red chips, however, the mean values and standard deviation almost coincide. Much of the data from either class lie within the bounds of the other class, and separation by a value range test is not possible. A test of the maximum likelihood type may be applied, because there are differences in probability between classes at all points except the curve crossing point, $x_R = 166$. The maximum likelihood test will assign the points to the class with the highest probability of containing that point, assuming equal a priori probabilities and equal loss functions. Thus a point value, x_R, of 164 would be assigned to class red because the probability of its belonging to that class is greater than of its belonging to class magenta. Similarly, a value $x_R = 168$ would be classed as magenta. Using this approach will mean that approximately half of the points in each class will be misclassified. One other approach may be used to help classify data which, from one set of measurements alone, are inseparable. This approach makes use of data taken over the same image, but with colored filters used to force separation of data sets on the basis of

selective filtration. Thus in the above case, where a red filter caused red and magenta data sets to be in close proximity, use of a blue filter forces separation. Figure 16 shows a two-dimensional presentation of the four data sets, white, yellow, red, and magenta with axes corresponding to red-filtered and blue-filtered transmissivity values. The rectangle containing the data points is centered on the mean value and is of width and height equal to plus or minus two standard deviations. Magenta and red remain inseparable when viewed from the x_R axis, but are easily separable along the x_B, or blue-filtered, axis. The principle of using data taken originally, or subsequently measured in, more than one spectral region is the multispectral principle. Its purpose is to allow efficient separation and classification of data with acceptable accuracy and minimum expense of computer and analysis time.

Discussions of data classification principles and methods may be found in References (10) and (11) and in the works referred to in their bibliographies.

III. APPLICATION OF DENSITOMETRIC ANALYSIS TO A HIGH-ALTITUDE COLOR-INFRARED PHOTOGRAPH

The basic method outlined in the previous chapters may be used to generate numerical data for automatic, computer-based classification of ground scene elements. As an example, relative light transmission measurements were taken on four types of scene elements of the color-infrared

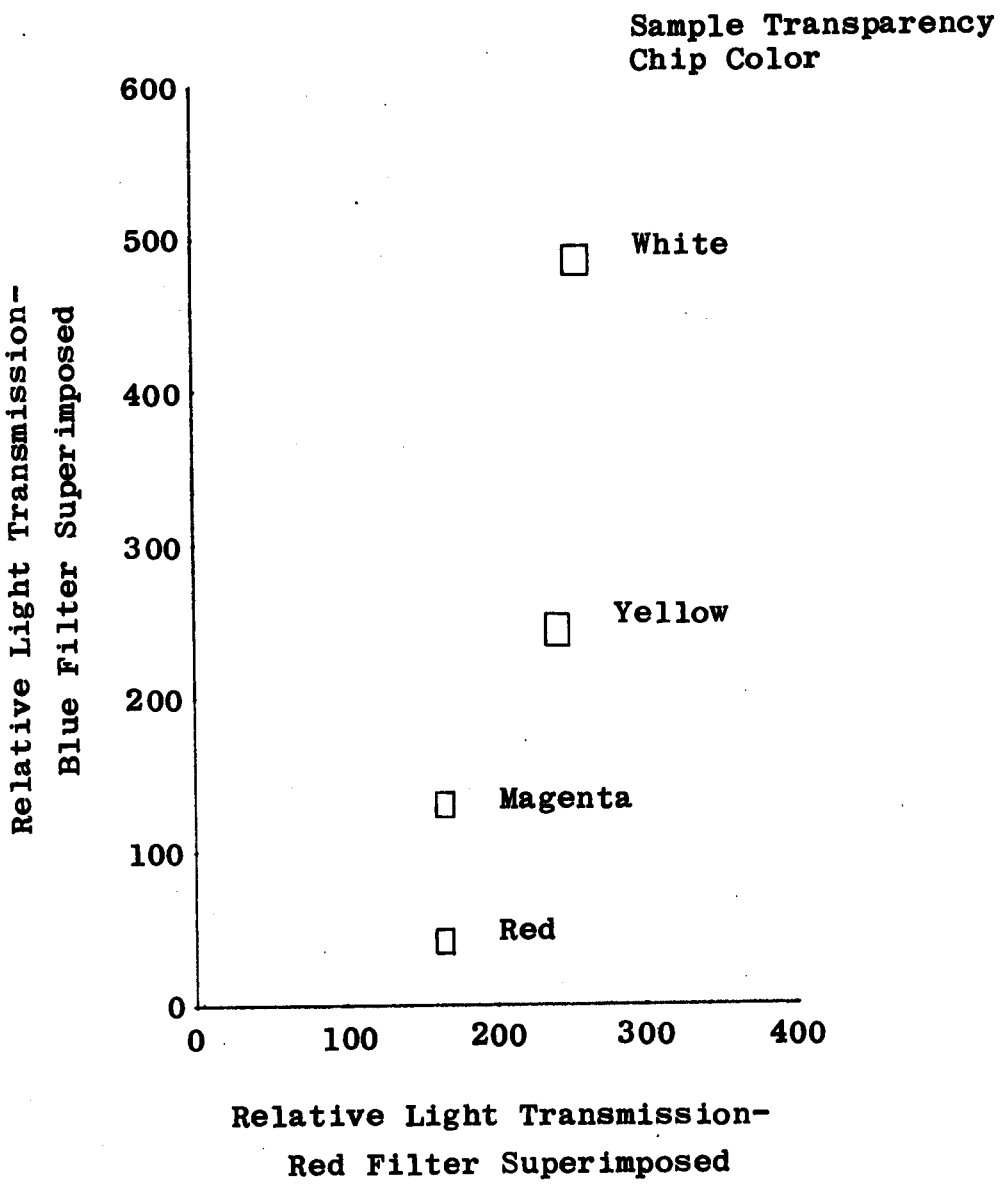


Figure 16. Use of two sets of independent relative light transmission measurements to aid in numerical classification of image elements.

transparency from which the print of Figure 8, page 15, was taken. The four types were dark red forest areas, green forest areas, pink fields, and grey fields. As mentioned earlier, these scene elements are evergreen stands, deciduous tree stands, fields with growth of small grains or pasture, and unplanted fields, respectively. Measurements of relative light transmission for each of these scene elements are tabulated in Table III and plotted in histogram form in Figure 17. For these measurements, the transparency was positioned over the central portion of the light table and the camera was positioned with its lens ring (lower edge) four inches above the light table surface. The analyzer digital meter was calibrated to give zero reading when the camera lens cap was in place (zero light transmission) and to read 1,000 when the point being digitized (cursor intersection point) was the brightest point on the image. The camera lens setting was f/3.5. Scanning of the image scene elements was accomplished by moving the cursor intersection point over each separate area in a pattern consisting of several lines spaced so as to avoid both overlapping of data points and too close an approach to scene element edges.

The four types of scene element may be classified numerically with measured transmission values from 0 to 60 corresponding to evergreens, from 60 to 200 to deciduous trees, from 200 to 500 corresponding to fields with growth of pasture or small grains, and values over 500 relating to unplanted fields. Extension of the foregoing method to

TABLE III

MEASUREMENTS OF RELATIVE LIGHT TRANSMISSION FROM FOUR SCENE ELEMENTS OF A COLOR INFRARED AERIAL PHOTOGRAPH TRANSPARENCY

	Field Description			
	Dark Red Forest	Green Forested Area	Pink Field	Blue-Grey Field
	33	96	416	564
	31	96	436	575
	35	74	418	578
	38	85	317	589
	39	73	433	590
	37	98	375	540
	32	93	389	558
	33	64	398	581
	44	71	394	597
	34	85	434	614
	47	99	430	617
	45	79	448	610
	33	97	447	600
	24	81	419	597
	37	92	427	602
	36	94	421	596
	32	68	375	601
	24	93	399	618
	28	72	373	609
	27	90	362	612
	29		337	582
	34		331	585
	28		403	554
	25		436	576
	24		435	547
	35		438	562
	36		433	
	29		326	
			429	
			425	
			387	
Mean values	33	85	403	587
Standard deviations	6	11	38	22

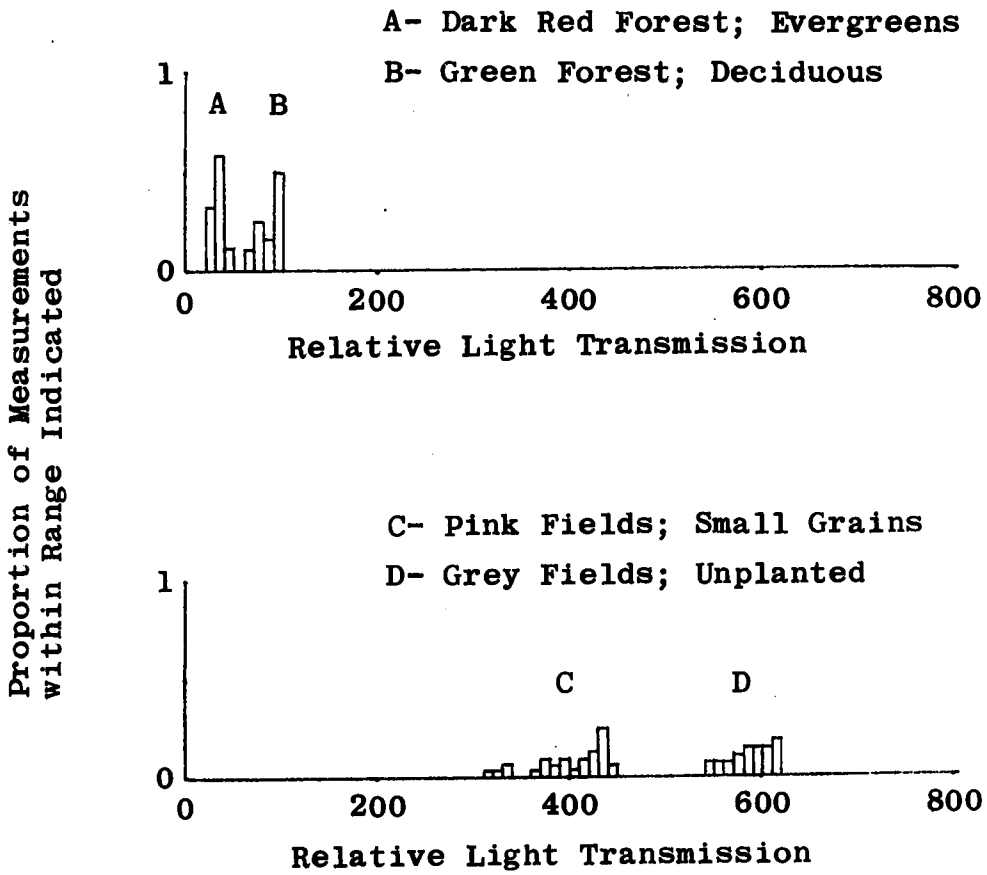


Figure 17. Histograms of relative light transmission measurements from four types of scene element in the color-infrared aerial photograph of wooded and cropland areas.

digital computer operation is straightforward, and allows very rapid image analysis and scene element classification.

In the analysis of any image, the ability of the scanning camera to observe accurately the variations of optical density, or relative light transmission over the image is of importance. The system capability in this regard is described in the following chapter.

CHAPTER VI

RESOLUTION OF THE UNIVERSITY OF TENNESSEE SPACE INSTITUTE TELEVISION DENSITOMETER

One factor of interest in the use of the television scanning densitometer is the resolving power, or the ability of the instrument to resolve fine detail. When examining a standard test chart transparency consisting of alternate black and white bars of varying width, it is observed that electrooptical scanning instruments often show a degradation in performance such that the instrument reads the densities corresponding to those actually present in the transparency down to a certain minimum bar width, and then begins to lose amplitude at the bright levels and to gain amplitude at the lower levels. The practical implication of such resolution performance arises in connection with measurements taken on high altitude photography. A field may show alternating bands of green, at high density, and grey at low density. If such bands or other similar sharp variations in density occur, then it is likely that the optical density measurements will be affected by amplitude loss to some extent. In general it is safe to assume that fields of nearly constant density and of width 1/150 of full scan width will be read with no more than 10 percent loss in amplitude, peak-to-peak. A discussion of photoelectronic imaging devices and their performance is found in Reference (12).

A summary of observed instrument performance characteristics is as follows:

Spot Spatial Resolution

Horizontal: 800 lines across the scan width.

Vertical: 67 lines per inch by the shrinking raster method. Normal operation 525 lines full scan height, with 2:1 interlacing, resulting in 260 measuring lines full scan height.

Edge Spatial Resolution

Horizontal: 75 black/white line pairs across full scan width.

Vertical: 87 black/white line pairs across full scan height.

Density Resolution

Estimated 0.025, from 0 to 2.25. Estimated precision of scale reading plus or minus 0.1 percent full scale.

Repeatability

Repeatability of the measurements of a data set is within the limits of precision with which calibrations can be reset; approximately 0.1 percent full scale.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Aerial photography has been used for several decades as a source of information for mappers. The advantages of perspective and area coverage have made aerial surveys a valuable and economic tool in the generation of standard topological maps as well as in the preparation of woodland and cropland surveys. Much of the value of aerial photography has depended on the ability of the interpreter to make detailed measurements and object observations on the photographic material obtained in the aerial survey. Recent developments in high-altitude aircraft and spacecraft operation have made possible the acquisition of aerial photographic imagery from very high vantage points, thus extending area coverage, and, in the case of spacecraft, making frequent repetitive surveys possible. Two effects of the use of very high altitude vantage points and of frequent surveys are that much of the object detail formerly relied upon in photointerpretation is lost, and that photographic imagery production rates increase drastically.

The loss of detail in imagery obtained from very high altitudes causes the interpreter to rely on color and brightness factors associated with overall ground scene characteristics, rather than on the ability to observe and measure fine detail. Woodland and cropland areas are of substantial

size, even in very high altitude imagery, and exhibit unique color and brightness values characteristics of each area. Reliance must be placed upon these color and brightness factors for ground scene element identification.

The emergence of color and brightness factor importance in aerial imagery interpretation has the advantage that such factors lend themselves easily to automatic image reading methods. Automatic image scanning devices measure the amount of light coming through a transparency of an aerial image and are capable of recording color and brightness factors of the ground scene in terms of the color and optical density factors of the transparency. These devices are capable of scanning and recording measurements of an entire image in times on the order of seconds, and are thus well suited for use with computer-based automatic classification of the ground scene elements observed in terms of measured numerical values of the colors and optical densities found on the image. The availability of imagery of Earth's surface taken from very high altitude at frequent intervals, coupled with high-speed automatic interpretation of the imagery for ground scene element classification, makes possible world-wide surveys of resource conditions on an accurate and timely basis.

The automatic scanning of imagery is accomplished at The University of Tennessee Space Institute with a television densitometer. This device uses a standard Vidicon television imaging tube to convert color and optical density

factors of photographic transparencies into electrical signals which are recorded digitally for use in numerical classification methods. The electrical signal may also be examined on a cathode ray tube display, which shows the optical density factors of an entire image in terms of cathode ray tube beam deflection, or these same factors may be color-coded and displayed on a modified color television set. This latter display allows viewing a scene in terms of its brightness factors as well as in its original appearance as a video image.

A demonstration of the use of the television densitometer in measuring and recording scene optical density factors and in numerical classification of scene elements on the basis of those factors leads to the conclusion that the UTSI television densitometer is a very capable instrument in the automatic analysis of remote sensing imagery. Further work in improvement of instrument performance and in development of computer-based numerical ground scene element classification methods is continuing at The University of Tennessee Space Institute.

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VITA

James Phoebus Rhudy was born in Sebring, Florida on November 28, 1932. He attended elementary schools in West Palm Beach and was graduated from Palm Beach High School in 1950. The following September he entered Palm Beach Junior College, and in June 1952 he received the degree Associate in Arts. In September 1952 he entered the University of Florida and received the degree Bachelor of Aeronautical Engineering in August 1954. He was employed by ARO, Inc. from August 1954 to July 1970, at which time he entered the Graduate School at The University of Tennessee Space Institute. He received the degree Master of Science with a major in Mechanical Engineering in December 1974. He is ordained Deacon in the Episcopal Church.

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