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Microdensitometer Applied to Land Use Classification

Initial exploratory studies were conducted in an effort to automate the interpretation of land use classes from aerial color photography.

(*Abstract is on page 297*)

* Deceased.

Introduction

Can photo interpretation be simplified and automated to determine land use? This paper describes an attempt to resolve this question by using a scanning machine on color film exposed over 10 different land use types. The classification of land use is closely connected with the national forest inventory and is an important part of the photo interpretation task in forest survey.

At present, the fundamental acquisition of land use data is by means of aerial photography. The separation of land use classes is accomplished by superimposing a dot grid on aerial photographs and visually identifying from the photograph the land use coincident with each superimposed dot. Various classifications are thus derived when the data are submitted to normal statistical analysis. For an area the size of a state, several thousand photographs are required. Therefore the task of analysis involves counting dots and identifying related land use for several hundred thousand bits of data.

A considerable saving in man-hours of handling and interpreting aerial photographs would be realized if this task could be expedited and partly automated. An automatic scanning microdensitometer equipped with an analogue-to-digital-converter might meet this requirement. Digital data could be readily analyzed by normal digital computer techniques and land use classes produced. Tests to determine the feasibility of such an application were undertaken jointly by the Forest Service, U. S. Department of Agriculture and Photo and Repro Division of General Aniline and Film Corporation.

At the outset it was assumed that the natural differential reflectivity of light from various land uses could be readily recorded on aerial color film and that analysis of the color images by densitometric methods would provide the data necessary for classification. Color film was selected to record the land use classes because it adds two dimensions of measurement, hue and chroma, not available on panchromatic film.

A Macbeth-Ansco Model 12A Color Densitometer was used in preliminary tests in an attempt to identify different tree species from color aerial photographs exposed at 1:1188 scale on 70 mm. Super Anscochrome Color Film.[1] These tests indicated that the size of the aperture, which determined the

[1] Mr. William A. Fischer, Geological Survey, U. S. Dept. Int., generously permitted the use of the densitometer installed in the U.S.G.S. offices.

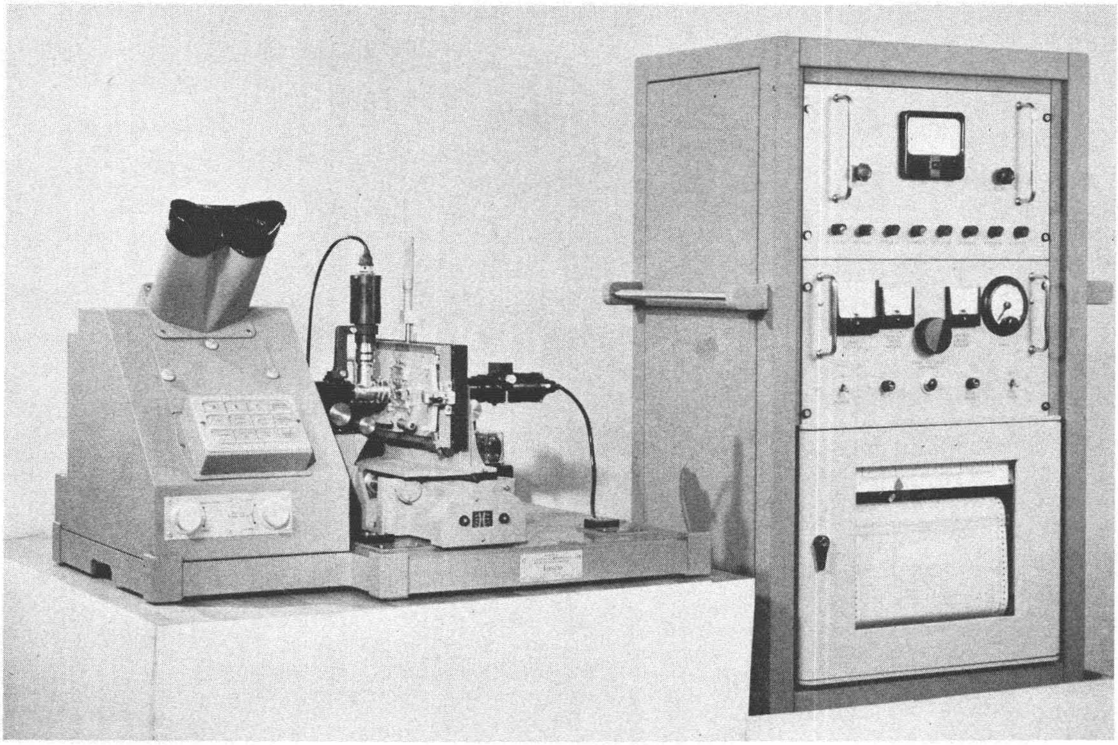


FIG. 1. GAF-Ansco Model 4 automatic recording microdensitometer.

effective area under observation, was a highly significant data distortion factor. They also showed that the accuracy of the data improved as the aperture size was decreased from 4 mm. to 1 mm. diameter. However, even at 1 mm. aperture, the best reliability of the results did not exceed 25%. It was found that the variance within measurements of a single tree species was greater than that between species even at the smallest aperture. Since a 1 mm. aperture was the smallest size that could be effectively used with a color macro-densitometer, further tests using a microdensitometer were indicated.

Microdensitometry is the technique of measuring either the reflection or transmission density of microscopically small image areas.[2] The microdensitometer (Figure 1):

1. looks at a very small portion—as little as 1 micron diameter—of a photographic image at spectral levels selected to be compatible with the sensitivity levels and dye component spectral characteristics of the photographic materials,
2. reads the optical density of the image by means of a scanning optical system and photo multiplier—log amplifier measuring system,
3. scans the sample at a uniform rate, as slowly as 10 microns per minute or rapidly as 80 millimeters per minute,
4. presents the data graphically on a strip chart or, when used with analogue converter, it presents data digitally to a computer for reduction and analysis.

[2] Derr, A. J., Ansco Division, General Aniline and Film Corp. "Application of a microdensitometer to photo-data assessment."
Flynn, F. M., Photo and Repro Div., General Aniline and Film Corp., "Forensic microdensitometry."

ROBERT C. HELLER

Preliminary tests of several subjects were made by Ansco of 70 mm. color films supplied by the Forest Service using the GAF Model 4 Automatic Recording Microdensitometer. Believing that these early efforts showed the definite possibility of the use of such instrumentation, the Forest Service and Ansco decided at a joint conference that a limited problem in photo interpretation would be selected for investigation and submitted to analysis by automatic instrumentation. For this problem, ten land use classes, commonly identified on small-scale photographs by photo interpreters, were chosen. These included two forest classes and eight non-forest classes. Specific areas were photographed to show contrasting forest and non-forest classes. The forest classes were:

1. even-aged conifer stands, and
2. even-aged mature hardwood stands

The non-forest classes were:

1. macadam roads
2. macadam airfield runways
3. concrete roads
4. water bodies
5. marshes
6. newly plowed fields
7. improved pastures, and
8. fallow fields

Collection of Data

Areas representing the above land-use classes were photographed on 70 mm. Super Anscochrome Film in early August 1962 at a scale of approximately 1:1188. In order to reduce the effect of variables (light, sun angle, moisture, etc.) as much as possible, all areas were photographed on the same film as quickly as possible (approximately one hour during mid-day). The areas photographed were inspected on the ground to insure that they were of the land-use types wanted.

After development the film was taken to GAF, Photometric Systems Engineering, Binghamton, New York for testing on the Model 4 Microdensitometer. Scribe marks were made on the film to locate the trace areas and to permit subsequent visual evaluation of the same areas. Color filters, compatible with the spectral sensitivity levels of the three emulsion layers of the film, were introduced separately into the microdensitometer system. These were blue (436 mμ), green (546 mμ), and red (644 mμ). Each filter produced a readout of density for a particular color on a strip chart recorder. The traces from the recorder charts formed the basic data which were analysed for separating land use classes and for determining the optimum aperture area and geometry for each of the following three tests.

Test of Aperture Size—Test 1

Since previous experience indicated aperture size to be significant, it was decided that the first step of the program would be to test the effect of variations in aperture size on identification of three land-use classes:

1. Macadam runway
2. Improved pasture
3. Hardwood forest

The apertures used were the six standard sizes with which the GAF, Ansco Model 4 Automatic Recording Microdensitometer (Figure 1) is usually equipped.

Three round and three slit apertures were used. These apertures will be referred to in Test 1 by number as shown in Table 1.

The smallest round aperture, 4, was discarded because the readout density levels exceeded 4.0, the maximum scale value on the chart paper.

For replication, three different scans were made across one frame of film for each of the three land-use classes. Readings of mean optical density values for each of the three colors, red, blue and green, were taken from each strip chart by a visually placed horizontal straight line through the apparent mean of the data. This method seemed appropriate because it eliminated the need of reading a large number of values off the charts. In this procedure allowance was made for various occurrences in the photographs such as, white streaks in the runway, grass strips in the runway, cracks, etc.

On the traces of the hardwood forest a different sampling procedure was used. In this case the images on the film consisted of highlighted areas which were the tree crowns and deep shadows cast by the crowns. Since the crowns were of most interest, it was decided to measure the average density value

Table 1

Identification of Test Numbers

No.	*Shape*	*Size in Inches*	*Effective Aperture in Microns*
1	slit	0.01×0.750	1×75
2	slit	0.050×0.750	5×75
3	slit	0.200×0.750	20×75
4	round	0.02	2.0
5	round	0.049	4.9
6	round	0.197	19.7

for each of six trees, not necessarily of the same species.

Each of the readings was then corrected for previous machine calibrations as follows: blue—0.72, red—1.10, and green—0.20. Hereinafter, these corrected values will be referred to as *zeroed* values. The analysis was made on these zeroed valued (mean density).[3] Higher standard deviations were found to be associated with the hardwood forest densities than with the pasture or runway densities. Figure 2 is a graph of density versus aperture area for this test. Considering the random variables involved, a visual inspection of Figure 2 indicates that the only apparent effect of aperture area on density is the expected exponential decrease of density as aperture size increases. This was substantiated by subsequent analysis which is described later in this report.

[3] The authors gratefully acknowledge the statistical guidance offered by John L. Seliskar and much of the computational work by Mrs. Gloria Richardson, Forest Research, Forest Service, Washington, D. C.

Since the primary problem is the discrimination or classification of various land-uses, the important measure is the distance or spatial orientation among density levels for each land-use within an aperture size. The only important effect that aperture would have in this study is that aperture size might affect these spatial distances among density levels within an aperture size. Because of this fact it was decided that, rather than use analysis on the zeroed density values, it would be much more meaningful to analyze the differences in density values among land uses over the range of aperture sizes and to study the effect of aperture sizes on these differences. Two differences were chosen arbitrarily: ΔP, the zeroed density difference between traces from pasture and runway within color; and ΔH, the zeroed density difference between traces from hardwood and runway within color. Each Δ value was transformed by adding 1 to get rid of negative values in the analysis. This transformation has no effect on the results of the analysis of variance because the analysis of variance is in-

ABSTRACT: *The fundamental acquisition of land use data from aerial color photographs would be expedited if the process could be automated. However, color density alone does not seem to offer a solution to differentiate land use on the photographs. Although aperture size affected density readings, no improvement in land use discrimination could be ascribed to the aperture area. Moreover, the geometric shape of the microdensitometer aperture (circular, slit or square) was of little or no significance. Density differences in the blue region of the spectrum offered more possibilities in separating ten land use classes than did the red or green.*

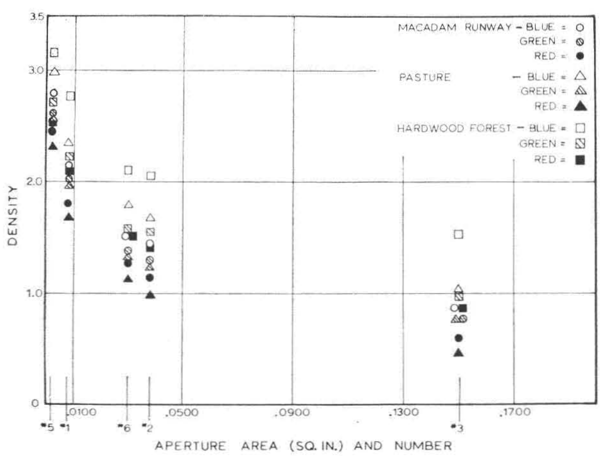


FIG. 2. Density as a function of aperture area.

TABLE 2

APERTURE AREA AND GEOMETRY

Area number	1	2	3
Relative area	1	5	10
Effective area in microns	0.00188	0.0094	0.0188
Actual Aperture Area (in inches)			
Geometry			
Round	0.049	0.109	0.155
Square	0.044	0.097	0.137
Rectangle	0.0025×0.75	0.0125×0.75	0.025×0.75

variant under a non-singularlinear transformation.

Analysis of variance seemed appropriate to use on this data. It is a well known statistical technique developed by R. A. Fisher which permits an investigator to compare several treatment effects within an experiment (in this case, aperture size, shape, and filter color). It assumes a normal distribution of values and employs the method of least squares to account for variation about the treatment means. The significance (i.e. no difference among treatments, highly significant difference, etc.) of the variation is determined by comparing a ratio value from the experiment with a ratio value from a probability table (known as an F-table). A standard statistical text which may be used as a reference is listed below.[4]

Because of missing observations in two of the apertures, No. 5 and No. 6, it was necessary for convenience to run the analysis on the cell means in order to avoid the complicated analysis strictly appropriate to the case of unequal numbers in the three-way analysis of variance. Assuming that the true three-way interaction was negligible and therefore represented experimental error, significance tests were made. All effects were significant at the .01 level. All but one of the two-way interactions were significant.

Thus, aperture size influenced the density readings significantly, but this test did not point out which aperture size was best for maximum discrimination. Since aperture size has a definite relationship to image size on the film, once the optimum aperture size is determined for a particular scale of photography, it is likely that, within the capabilities of a lens and film resolution system, smaller apertures could be used with resultant savings in photographic and interpretation costs.

[4] Snedecor, George W., Statistical Methods. Iowa State College Press Fifth Edition, 534 pp., Chapters 10–12 on analysis of variance.

While two different aperture geometries, namely, circular and rectangular, were used, it was not possible to assess the effect due to geometry. This effect, if it did exist, was completely confounded with the effect due to aperture area. This is quite evident in Figure 2. For this reason, it was decided that the effect due to geometry should be tested and hence Test 2.

APERTURE AREA AND GEOMETRY—TEST 2

The second test consisted of 81 observations taken under the following factorial conditions: three aperture areas, three geometries, three land-uses, and three colors—producing a total of 81 cells. The relative aperture areas and geometries are shown in Table 2.

Note that each aperture shape (geometry) was constructed to conform to identical aperture areas.

Again the zeroed density values were derived from the microdensitometer charts and organized by the factorial conditions shown above. The question to be resolved, as mentioned before, was whether or not geometry (configuration of the aperture) had an effect on discrimination among various land-use classes.

We were permitted once again to examine the effect of aperture area on discrimination. However, there was one difficulty—the lack of replication and the corresponding absence of a pure error term. The decrease in average density for increasing aperture area showed up again as in Figure 2. In view of this fact, the analysis of variance was carried out in terms of the same delta values that were used in Test 1, i.e., the values were derived by subtracting the runway densities from the pasture and hardwood densities. The first analysis was performed on ΔP and ΔH (the differences in land-uses). This was a four-way analysis of variance (three colors, three areas, three geometries, and two Δ-uses). The results showed all main effects, all first order inter-

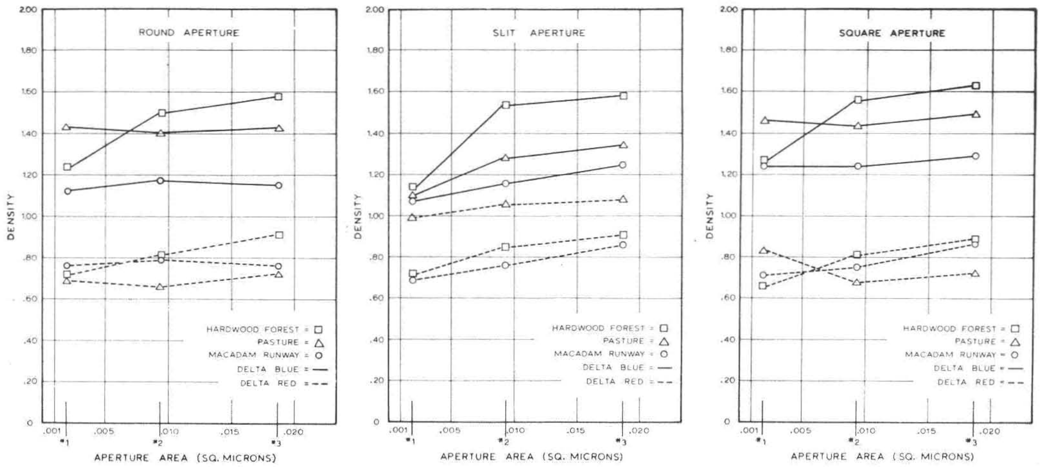


FIG. 3. Δ-blue and Δ-red density values for three aperture areas: *left*—round aperture only; *center*—slit aperture only; *right*—square aperture only.

actions, and two second-order interactions to be significant. These results agreed with those found in Test 1.

A second analysis of variance was made on the Δ-colors; i.e., both the red and blue densities were subtracted from the intermediate green density. The green density was affected less by aperture size or geometry than the blue or red and consistently fell between the blue and red densities. As before, a 1 was added to all data to avoid negative numbers. Again all main effects (color, aperture area, geometry, and land-use) were significant—all but geometry at the .01 level. Geometry was barely significant at the 0.05 level. Thus, when comparing color differences (i.e., ΔR and ΔB), geometry appeared to affect the density differences less than aperture size, color, or land-use. By inspecting the three parts of Figure 3, the best land use separation can be found on the left diagram which has the following characteristics: the largest aperture, 3, the round geometric configuration and the Δ-blue color. The square configuration was almost as good. As mentioned before, while this test had no real replication, the above data does indicate which combination of instrument physical attributes should separate land uses better than others.

Figure 4 consists of graphic representations of density values for three land uses, with

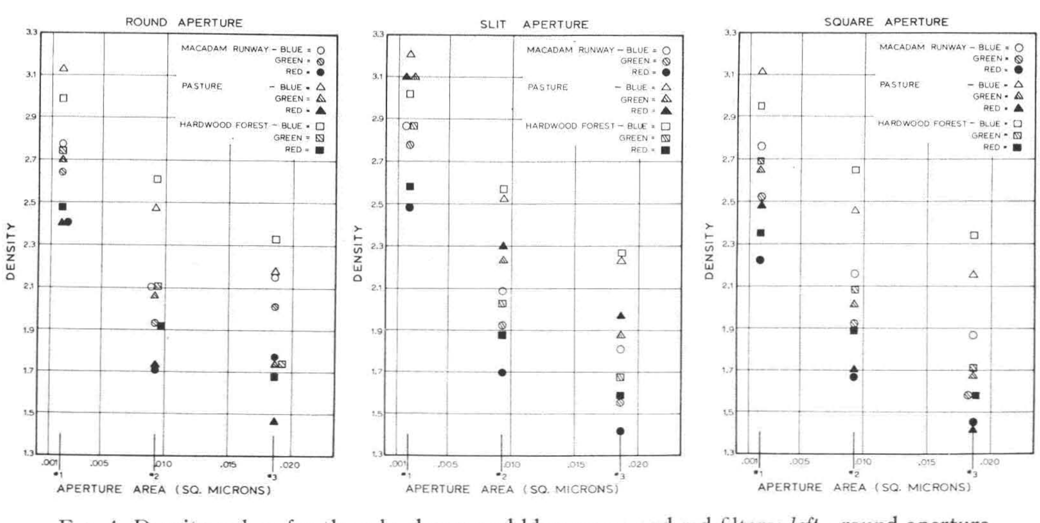


FIG. 4. Density values for three land uses and blue, green and red filters: *left*—round aperture only; *center*—slit aperture only; *right*—square aperture only.

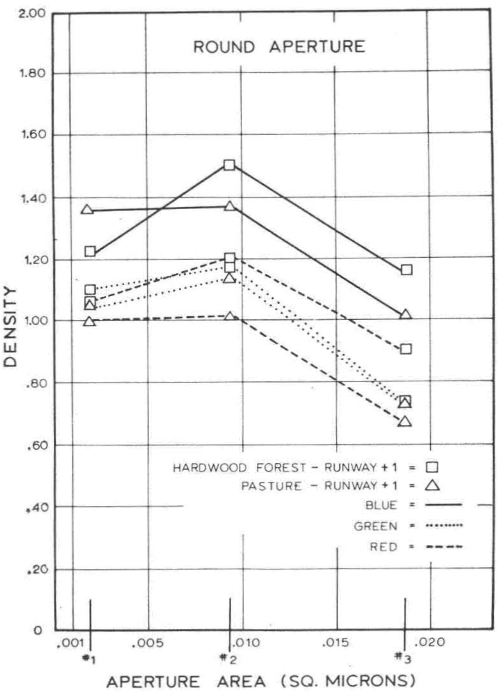


FIG. 5. Effect of three colors and three aperture areas on discrimination of two land uses—round aperture only.

blue, green, and red filters, with round aperture, square aperture, and slit aperture, respectively, and are shown separately in each illustration.

If density alone was considered, the best discrimination of land use appeared on Figure 4 when a blue filter was used with square apertures at all aperture sizes. The hypothesis assumed was that means having the greatest range in addition to being equidistant from each other were best. On this basis, the discrimination with the round configuration and largest aperture size was not as good as the square one.

In comparing two land uses when the runway density values were subtracted from pasture and hardwood forest density values, Figure 5 indicates that both the red and blue colors at the two larger apertures were better than the green.

The largest round aperture (0.155 inches) was chosen arbitrarily to determine whether the microdensitometer could be used to separate the 10 land use classes described in the introduction and forms the basis for Test 3.[5]

COMPARISON OF TEN LAND-USE CLASSES—TEST 3

Test 3 was undertaken to determine the feasibility of land-use identification by microdensitometric methods. The ten land-uses incorporated in the study are as follows: water, hardwood forest, Virginia pine, swamp, pasture, fallow field, plowed field, macadam highway, macadam airfield, and concrete highway.

Within each of the ten land-use classes a green, red, and blue color density trace was

[5] Subsequent analysis of Test 2 results showed that better results would have been obtained by using the largest square aperture.

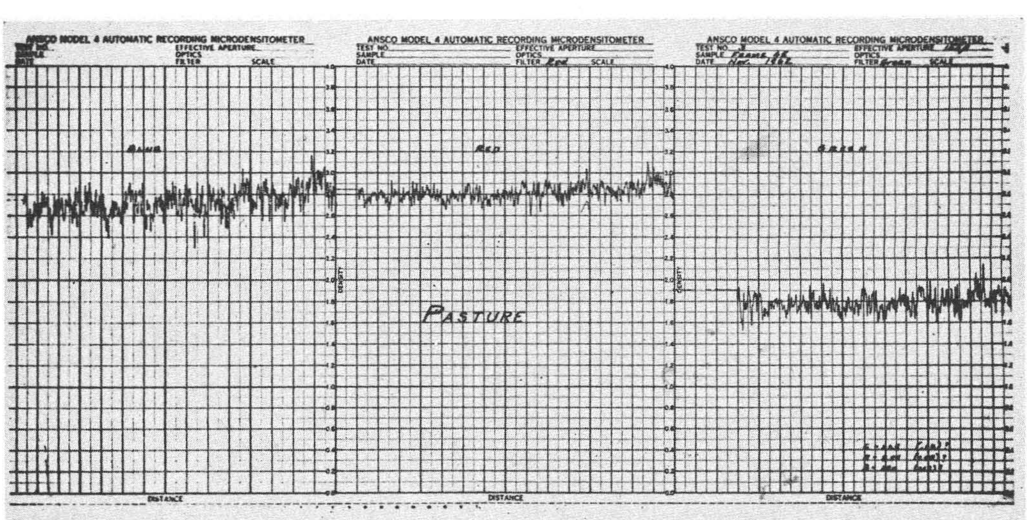


FIG. 6. Microdensitometer trace across one frame of Super Anscochrome film exposed over *pasture*, round aperture, 0.155 inches in diameter. Actual imagery appears below trace.

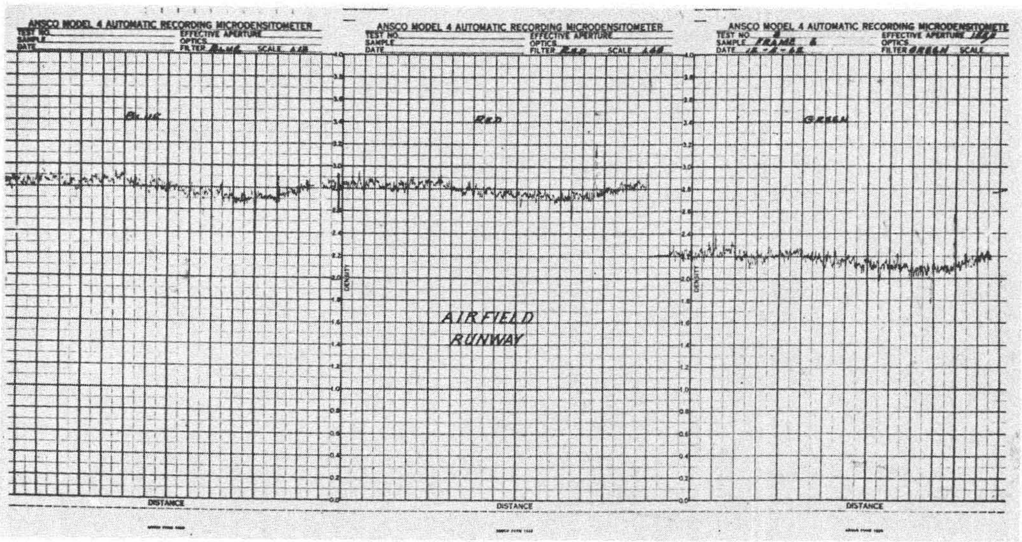


FIG. 7. Microdensitometer trace across one frame of Super Anscochrome film exposed over a *macadam runway*, round aperture, 0.155 inches in diameter. Actual imagery appears below trace.

taken on each of five sample frames of film. Thus, there were a total of 50 frames of film involved in this test. The round aperture, 0.155 inches in diameter was selected primarily on the basis of experience of one of the authors. The sample within each frame of film was, as before, a single trace, purposively selected, and run roughly two-thirds of the way across the frame. Figures 6, 7, 8, and 9 show the appearance of traces for pasture, runway, hardwood forest, and fallow field, respectively. The data values from the study were arranged by color within land-use and by sample number; only pertinent data such as photo-frame number, zero color value, and Δ-color value were tabulated.

The analysis of variance on the above data was made on the zeroed color density values. The first analysis was a two-way analysis of variance with color and use as main effects and a color-use interaction term. Both main effects and the interaction term were significant at the .01 level. The second analysis of variance was on the Δ-color, Δ-*R*ed and Δ-*B*lue, and land-use as main effects with a Δ-color-use interaction term. Δ values were

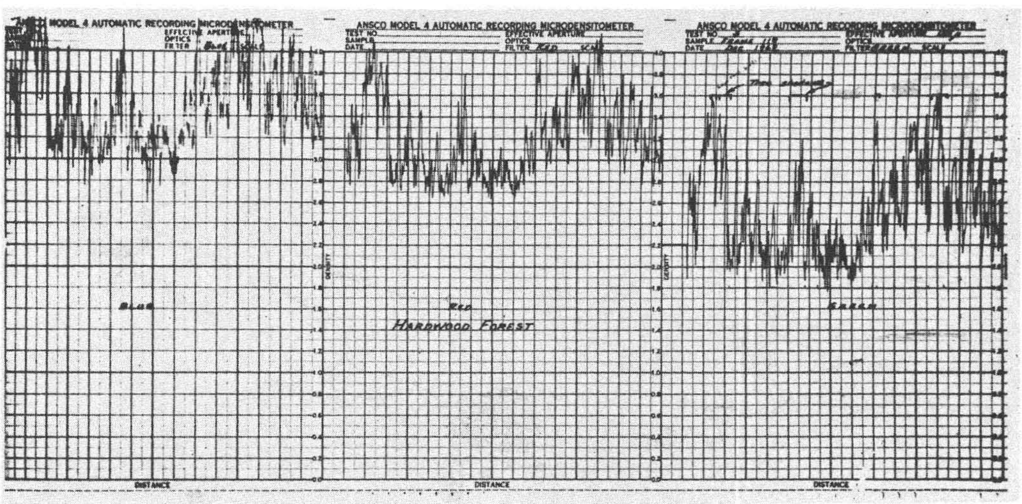


FIG. 8. Microdensitometer trace across one frame of Super Anscochrome film exposed over *hardwood forest*, round aperture, 0.155 inches in diameter. Actual imagery appears below trace.

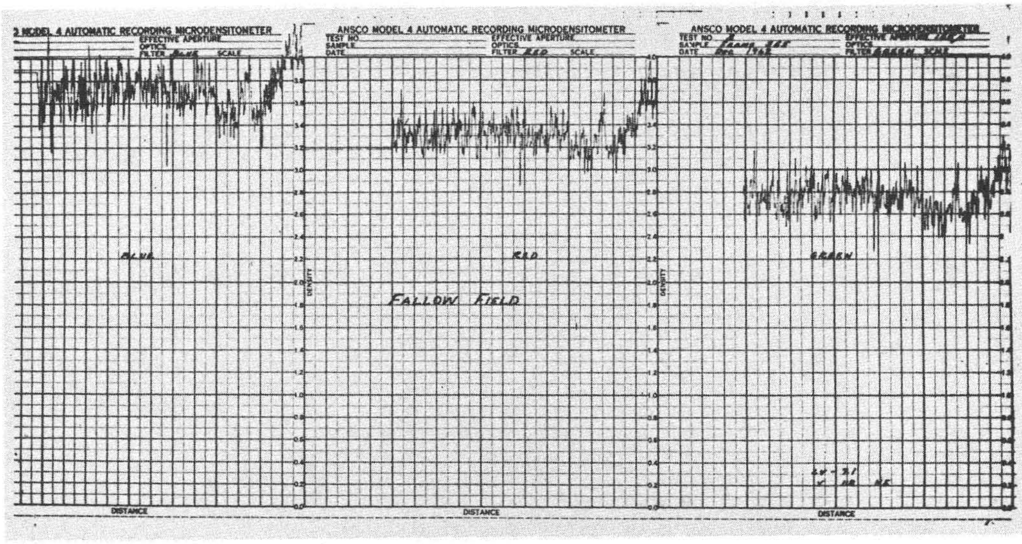


FIG. 9. Microdensitometer trace across one frame of Super Anscochrome film exposed over *fallow field*, round aperture, 0.155 inches in diameter. Actual imagery appears below trace.

again transformed by adding 1 to each to get rid of negative values in the analysis. Again both main effects and interaction were significant at the .01 level. The interaction term was much larger than in the previous analysis.

Figures 10a, 10b, 10c, and 11 show the mean color values of ten land use classes, with their corresponding standard deviations. These charts provide a visual presentation of the problem of land use discrimination or classification. On the basis of these figures, the blue densities shown on Figure 10a and the Δ blue densities from Figure 11 showed more promise than any of the other density combinations.

Figures 12a and 12b illustrate density as plotted by color and land use, respectively. Again it is apparent that the blue color exhibits the greatest range in density among the land uses tested. These charts point out why significant differences show up in both the main effects and also the interaction as computed in the analysis. Note the similarity in slopes of the lines, shown in Figure 12a, in the following land uses: swamp-fallow field; macadam highway-macadam runway; water (which was muddy)-plowed field; hardwood forest-Virginia pine forest. The concrete highway and pasture had entirely different density responses; the concrete highway was so low in density that it could be identified correctly 100% of the time. It is difficult to conjecture why the pasture was not comparable with the fallow field.

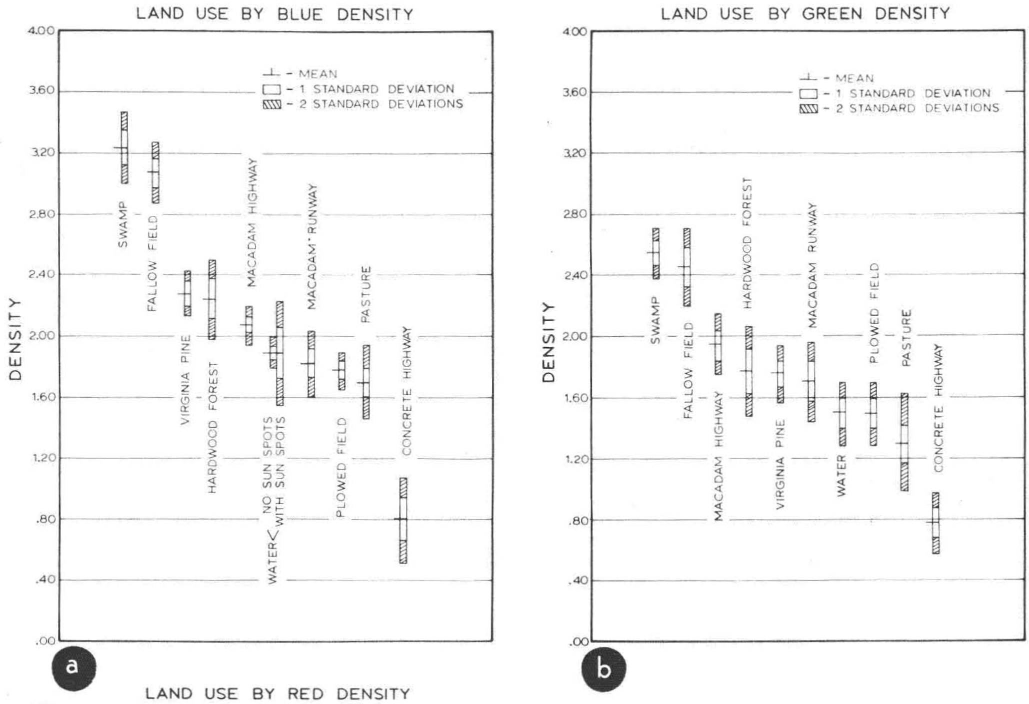
Some of the variation within each land use can be attributed to true differences which may be difficult to resolve in an automatic scanning system. For example: water is a subject where one would expect uniform light reflectivity and little variation between frames. Figure 13 compares densities from frame 84 where sunlight was highly reflected in a specular mode from each wave top (low density) with frame 90 where this reflection did not take place. Such reflections are more characteristic of sunlight than of the lighted material, i.e. water. This one low density frame is responsible for the large expected error around the mean for water. If many water samples were taken, polarized filters used on the camera, or photos taken with a low sun angle, this source of variation might be eliminated. Another method, automatic rejection of such data in a digital system, would reduce this error.

While absolute identification of land use is not possible with only color density as a measurement criteria, grouping of land use classes shows some improvement. In Table 3 the Δ-blue density is slightly better in the total use separation than the blue density alone. The Δ-red comparison offers no discrimination of land use at all.

A SUMMARY OF THE MICRODENSITOMETRY STUDY

The results of the three tests can be summarized briefly as follows:

1. Test 1 was designed to determine if aperture size affected density readings. Highly significant differences did show up among the five aperture areas and three land use classes. Den-



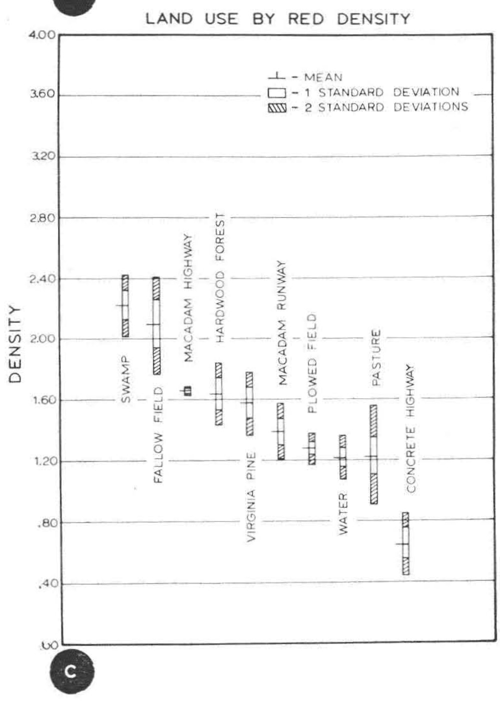


FIG. 10. Means and standard deviations of (a) blue, (b) green, and (c) red density by ten land use classes.

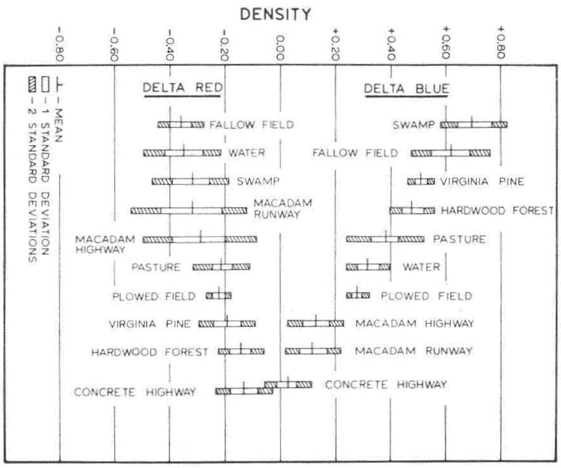


FIG. 11. Means and standard deviations of Δ-blue and Δ-red densities for ten land use classes.

sity decreased asymptotically as aperture size increased; however, no improvement in land-use discrimination could be ascribed to changes in aperture area within the size range normally associated with microdensitometric techniques.

2. In Test 2, it was again determined that aperture area significantly affected overall density readings, but that aperture geometry, while significant, had less affect on density than the other variables. The largest square aperture configuration with the blue or Δ-blue density value was better at separating land use than the smaller areas or the slit configuration.

This result would seem obvious in view of the established theory regarding granularity in photographic images.[6] Where images are large, as in the present case, a large aperture would be required to integrate enough individual signals to produce a characteristic "density." With photography having small images, i.e. high altitude photography, small

[6] E. W. H. Selwyn, *Photo. J.*, 75, 571 (1935).

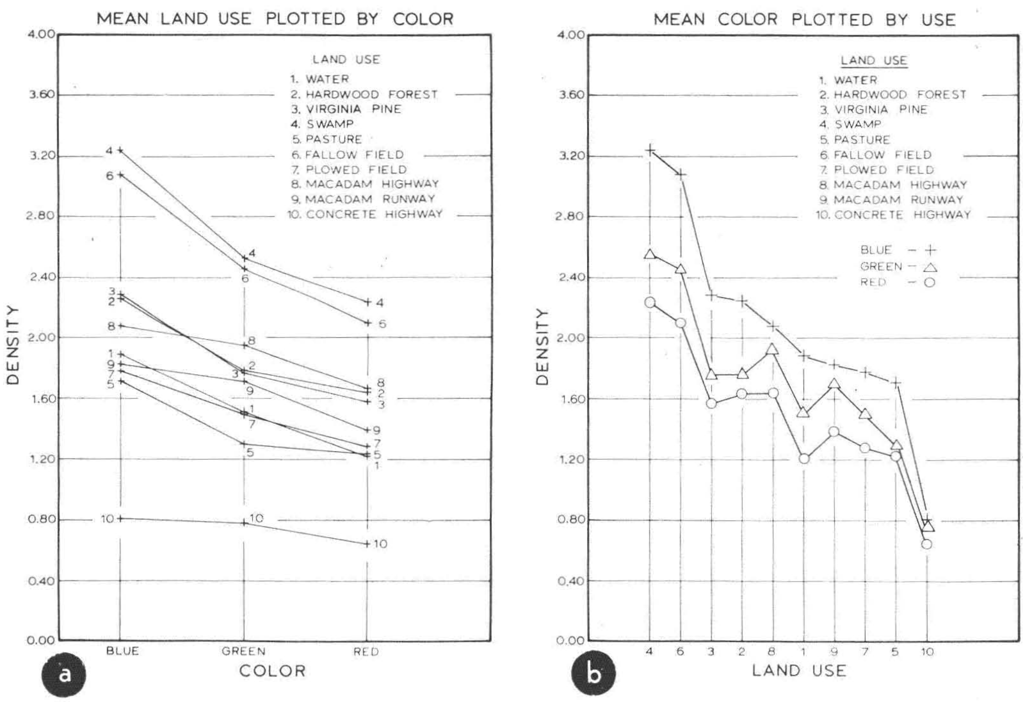


FIG. 12a. Mean land use plotted by color density; 12b. Mean color plotted by land use—arrayed by blue density.

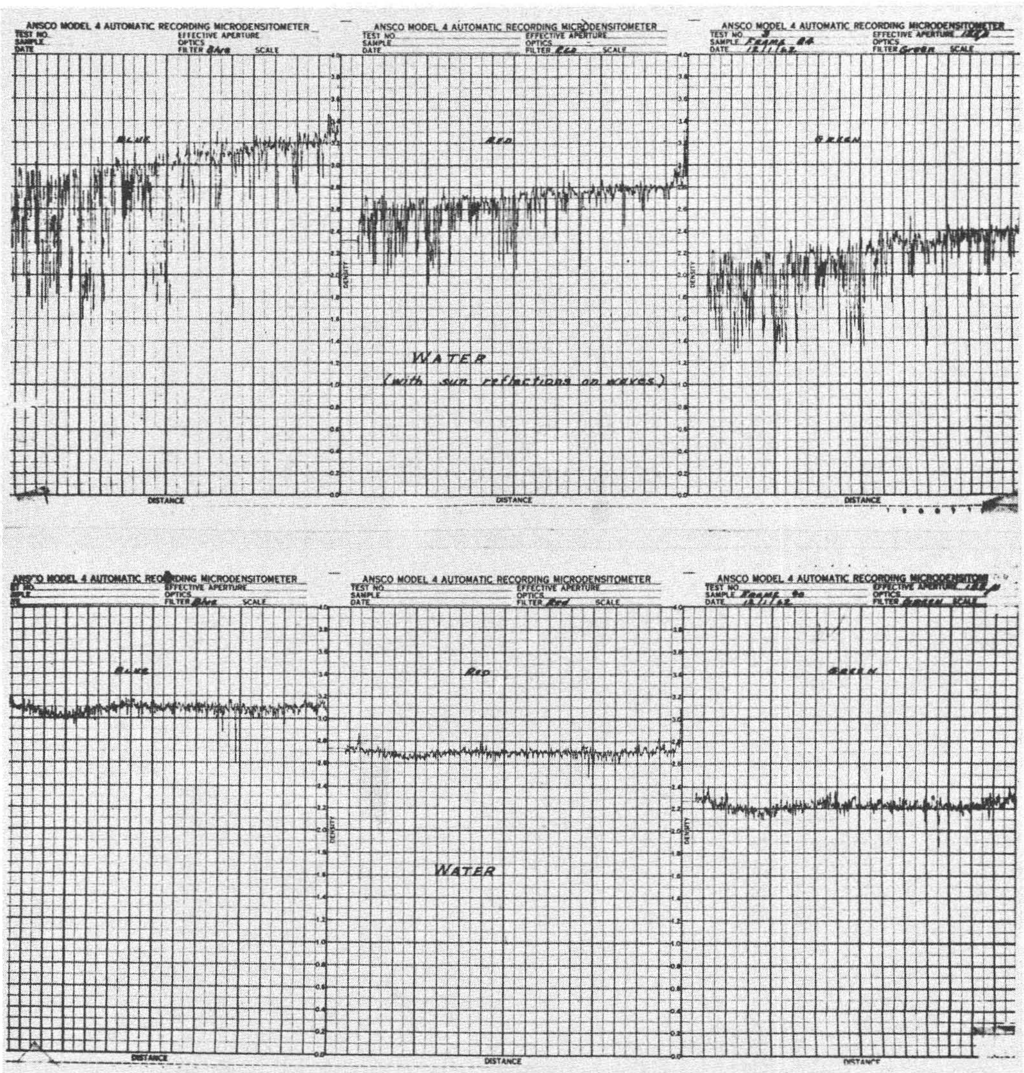


FIG. 13. Comparison of microdensitometer traces across two frames of Super Anscochrome film. Frame 84 is highly reflective and has a lower density than frame 90.

TABLE 3

NUMBER OF LAND USE TYPES THAT CAN BE DISCRIMINATED FROM NINE OTHERS AT TWO STANDARD DEVIATIONS

Land Use	*Density*				
	Blue	*Green*	*Red*	*Δ Red*	*Δ Blue*
Swamp	8	8	8	0	8
Fallow field	8	8	5	3	5
Virginia pine	6	4	4	0	6
Hardwood	5	4	5	1	5
Macadam highway	5	6	7	0	7
Water	3	4	6	0	7
Macadam airfield	5	3	4	0	7
Plowed field	6	4	5	1	7
Pasture	6	4	4	0	4
Concrete highway	9	9	9	1	7
Totals	61	54	57	6	63

apertures would be indicated. This is consistent with existing theory of image evaluation.[7]

The round configuration was almost as good as the square under the above conditions. In most cases, the green densities were very similar within each aperture size and offered little help in the way of land use separation. Replication on this test may have permitted more definite conclusions to be made about aperture geometry and size.

3. An attempt was made to separate all ten land uses in Test 3; the microdensitometer was equipped with the largest round aperture used in Test 2. Again the blue and Δ-blue densities offered more possibilities to separate land use than the red, green or Δ-red color values.

Using this measurement technique, only the concrete highway could be discriminated from other land uses 100% of the time. Certain land use *groups* could be distinguished from others 95% of the time but improved techniques are needed before the microdensitometer could be used for land use classification.

Conclusions

Color density alone does not offer a solution to differentiate land use on color aerial photographs. The results of these tests under very restrictive conditions showed that accurate classification was not achieved where color density was used. The number of errors would almost certainly increase as the restrictions on sampling were loosened to correspond with a reasonable operational procedure over wide areas.

These tests with the microdensitometer do suggest promising leads that should be investigated and procedures that may offer more conclusive results.

1. To standardize and reference all color photography, several exposures of a neutral gray surface (standardized photographic gray card) should be made on each roll of film and the film processed with a sensitometric strip. Such a procedure would permit the microdensitometer to be adjusted to a known system standard.
2. Inasmuch as the frequency and magnitude of the traces were very different from many of the land use classes, each land use may exhibit a distinctive frequency pattern. Thus, it may be desirable to tie in blue density with the amount and frequency of density change.[8]
3. In future tests on a microdensitometer, data should be taken with an analogue-to-digital converter and then printed out in digital form so that errors in graphing and errors in visual determination of mean values, etc., can be eliminated. Questions as to the speed of photo-interpretation and the adequacy of various size computers might be partially answered during this process.
4. All questions with regard to number of traces, length of trace, photo scale, and number of frames are as yet undetermined. Based on the variation among means of traces of the same land use class in Test 3 we speculate that a minimum of 100 replicates would be needed.

Further tests under controlled conditions might establish accurate density standards applicable to land-use, should eliminate measurement errors, and thus may improve operational results.

[7] G. C. Higgins, *Appl. Optics*, 3, 1, Jan. 1964.

[8] A similar approach was suggested by Dr. Azriel Rosenfeld in his 1962 article "Automatic recognition of basic terrain types from aerial photographs," Photogrammetric Engineering, vol. 38: 1, pp. 115–132 where he compared oscilloscope photographs of video traces made from photos of six different land uses.

Dixie, Utah Mapping Project

The Bureau of Reclamation announces that it will negotiate a contract requiring professional services, under Invitation No. DS-6211. Work to be performed comprises vertical aerial photography, supplemental control and topographic mapping of approximately 43,570 acres of the Dixie Project, Utah. The lands are located adjacent to the Virgin River from Hurricane, Utah, to Bloomington, Utah, and along the Santa Clara River from near Shivwits, Utah, to near Santa Clara, Utah. St. George, Utah, the principal city in the region, is centrally located with respect to the area to be mapped. It is anticipated that the work may be started on award, about February 25, 1965, and must be completed within 150 days. Topographic maps are to be prepared to a scale of 1:4,800 with a 2-foot contour interval. The Government is establishing all primary horizontal and vertical control in the area. The contractor will be required to set paneling and establish necessary horizontal and vertical photo control. Photogrammetric bridging or analytical aerial control methods may be used for such horizontal control, but vertical ground photo control must be established by ground surveys.