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Terrain Classification Using Color Imagery

Algorithms are described which permit classification of terrain features from 1:100,000 scale color photography with an accuracy of 97 percent.

Introduction

On October 9, 1973, Rome Air Development Center (RADC) accepted delivery of an experimental photointerpretation console designed for analyses of color film imagery. Delivery of the interpretation console represented the culmination of seven years of research in the development of interpretation techniques for color film imagery.[1-10]

Abstract: *Algorithms have been developed to permit classification of metal, soil, pavement, cultivated fields, and vegetation elements from standard color film imagery. The analyses are significant because the algorithms are independent of sensor and atmospheric conditions. The algorithms thus remove the necessity for a new training data set for each data collection mission. Terrain classification from the algorithms was accomplished to 97 percent accuracy using imagery at scales as small as 1:100,000 taken from altitudes in excess of 50,000 feet.*

The principal elements of the new interpretation methodology involve the measurement of brightness differences which are contained in the three layers of the color film and which can be related to physical properties of the scene; a unique process for removal of atmospheric and exposure variables from the image so that the interpreter can confidently associate image brightness effects solely with the properties of the scene under study;† and a method for displaying image brightness variations in the form of the relative values, or ratio, of brightness between any two of the three film layers.[4] The ratio display has been found to be a most effective and accurate approach to interpretation of the spectral brightness differences contained within the color film. The experimental photointerpretation console integrates all of the techniques and concepts into a device which makes the interpretation process convenient and efficient. A photograph of the interpretation console is contained in Figure 1.

The operation of the interpretation console is described in detail by Smith *et al.*,[4] and Walker *et al.* [7] The operation typically involves five steps: (1) visual interpretation of the imagery at the console light table; (2) calibration of the imagery in order to remove atmospheric and processing effects by use of a micro-densitometer incorporated into the

† U.S. Patent 3,849,006

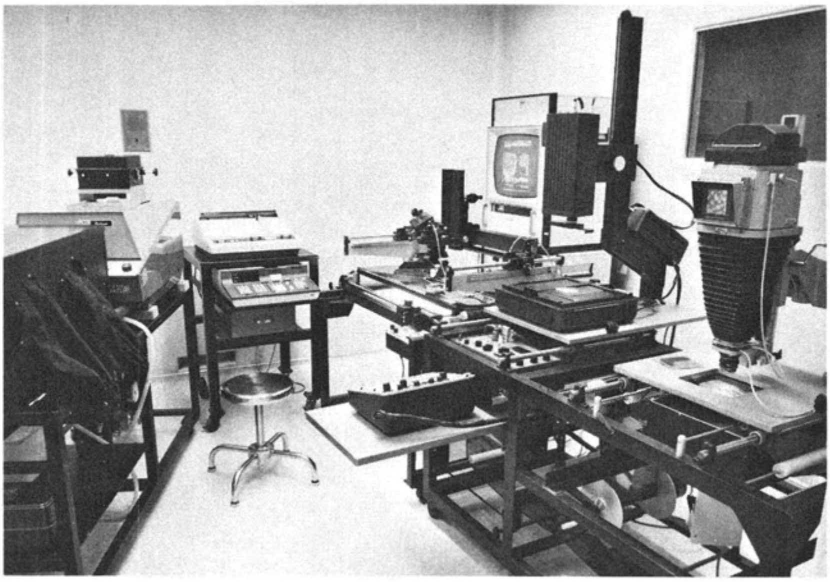

FIG. 1. The photometric interpretation console.

viewing stereoscope; (3) densitometric analysis of the color, or photometric, differences on the calibrated imagery; (4) generation of displays of photometric differences for individual film layers or combinations of film layers; and (5) comparative analysis of the photometric information with visual interpretation and background data.

During the development of the interpretation console, the photometric interpretation techniques were applied to a number of problems in order to evaluate the usefulness of the photometric approach and define the capabilities required of the various components of the console. These analyses included a mapping of water quality parameters such as chlorophyll, lignin, and humic acid;[5,11] a detection of vegetal stress and disease, including damage by sulfur dioxide,[12] disease and insect infestations;[10] an evaluation of the condition of concrete surfaces such as airport runways and roadways, including a delineation of regions of cracking and spalling;[7,8,10] a specification of soil moisutre and drainage flow;[3,8] and an identification of materials and material properties, such as metal discrimination and soil or rock texture.[7,10] The results of these analyses revealed that sensor and atmospheric parameters could be accurately removed from color film imagery and that consistent measures of terrain reflectances could be obtained.

A major problem in terrain classification is the necessity for developing a training data set for each data collection mission, because of changes in atmospheric and imaging conditions. Development of the training data set is costly and time consuming. Classification algorithms which would be valid for a wide variety of atmospheric and imaging conditions would represent a significant improvement in terrain mapping procedures.

In this paper we demonstrate that such classification algorithms can be developed for six simple terrain features: metal, water, pavement, soil, cultivated fields (light vegetation), and vegetation (dark, forested areas). (See Table 1.) These six object types can be distinguished easily by eye, provided the colors of the objects are not significantly modified by effects such as atmospheric scattering or the conditions of film processing and exposure. The image calibration technique measures atmospheric and processing effects and accurately determines the color or reflectances of objects from the color film record.[4,5] Therefore, we would expect classification based on reflectances obtained from color film to be very accurate.

Because of the simplicity of the classification categories in Table 1, the algorithms developed are relatively independent of seasonal and geographic parameters such as gross changes in soil moisture and soil type. (We exclude, of course, the autumnal change of color of vegetation.) More detailed classification schemes will probably have to in-

TABLE 1. MAPPING CLASSES

Metal
Water
Pavement—any concrete, asphalt, or gravel surface, including roofs
Soils and Sand—any bare soil element
Cultivated Fields—lighter vegetation, including pasture, graze, and grasslands
Vegetation—darker vegetation, primarily forested land

corporate seasonal and geographic effects to some degree. Even in these instances, classification from algorithms independent of atmospheric and imaging conditions will constitute a significant improvement in terrain classification procedures.

METHODS

Five areas within New York State were selected for study in the terrain classification analyses. These areas were centered on or near (1) Griffiss Air Force Base, (2) Verona, (3) Stockbridge, (4) the power plant at Schaghticoke, and (5) the railroad yards at Utica. The five targets were selected to provide as diverse a set of urban, industrial, rural, and agricultural features as possible. Mapping capability was evaluated for two map types: (1) a map 10 km on a side at 30 meters resolution; and (2) a map 0.6 km on a side at 5 meters resolution.

The Griffiss, Verona, Stockbridge, and Utica areas were overflown at 1:100,000 scale from 50,000 feet. These four sites can be contained within an equilateral triangle

FIG. 2. Scene classification site—Griffiss Air Force Base. (Reduced 50 percent. *Ed.*)

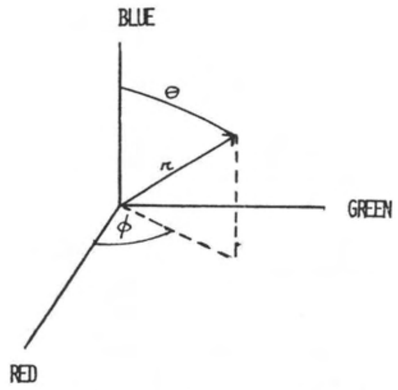

FIG. 3. Coordinate system used for the classification algorithms.

of approximately 30 km on a side. The Schaghticoke site, 160 km from Griffiss AFB, was overflown on a different day at 1:100,000 scale and 1:30,000 scale (15,000 feet). The film utilized was standard Ektachrome MS2448. Analyses of the Schaghticoke site were performed on the 1:30,000-scale imagery, primarily to investigate the possible increase in accuracy which could be obtained from lower altitude imagery (less atmospheric effects). A black-and-white copy of the 1:100,000 imagery over Griffiss AFB is given in Figure 2.

Classification algorithms were developed by studying almost 1,000 areas on each of the Schaghticoke and Griffiss AFB scenes. The areas were carefully selected to be well outside the areas to be mapped at Schaghticoke and Griffiss. Each object point was reduced to its red, green, and blue reflectance values by the photointerpretation console. The color space consisting of the red, green, and blue octant was described in terms of spherical coordinates (r, θ, ϕ,) (Figure 3). The parameter r is thus a measure of total brightness; the parameter θ is a measure of the amount of blue reflectance contributing to the brightness of the object; and the parameter ϕ is a measure of the relative amounts of green and red reflectance contributing to brightness.

The classification algorithms are contained in Table 2. The algorithms define areas of the (r, θ, ϕ,) space in which each object class is found. For example, the metal signatures require that a metal be at least of a certain brightness (r>0.22); that the blue component of brightness be at least a certain size (the θ rules); and that there be a balance between the amount of red and green in the object (the ϕ rules). The latter proportion of red and green stems from the fact that metals are white, or approximately flat spectrally.

A three-dimensional display of the volumes of color space would be extremely difficult to construct. Some feeling for the volumes can be obtained from the (θ, ϕ) and (r, θ) plots of Figure 4.. The regions of the two spaces in which objects of a certain class can be found are outlined. For an object to be in a certain class, it must be within the delineated regions on both plots.

The volumes of color space defining object classes are not exclusive, i.e., they have some overlap. The overlap primarily occurs between metals and pavements (bright concretes), cultivated fields and water (turbid, green ponds), and soils and pavements

TABLE 2. PHOTOMETRIC SIGNATURES

Class	ϕ	θ	r
1. Metal	$<-1.31\theta+2.24$	$<$ 1.50(If $r>0.50$) $<$ 1.07(If $r<0.50$)	>0.22
3. Water	$>-0.37\theta+1.41$ If$\theta>0.97$, $>$ $0.69\theta+.56$ or <1.07	$<$ 1.26 $<-22.7r+2.5$	—
5. Pavement	$>$ 0.69 $<$ 0.92 $>-1.12\theta+1.71$ $<-0.95\theta+1.88$	$>$ 0.96(If $r>0.22$) $<$ 1.13 $>-22.8r+2.51$	—
7. Soil and sand	$<$ 0.820 $>$ 0.620	$<$ 1.33 $>$ 1.01	>0.14
8. Cultivated field	$<$ $0.27\theta+0.80$	$>$ 1.00 $<-4.2r+1.97$ $>-11.2r+1.73$	—
9. Vegetation	$>$ $0.26\theta+0.81$ $>$ $0.17\theta+1.22$ $<$ $0.690\theta+0.55$	—	

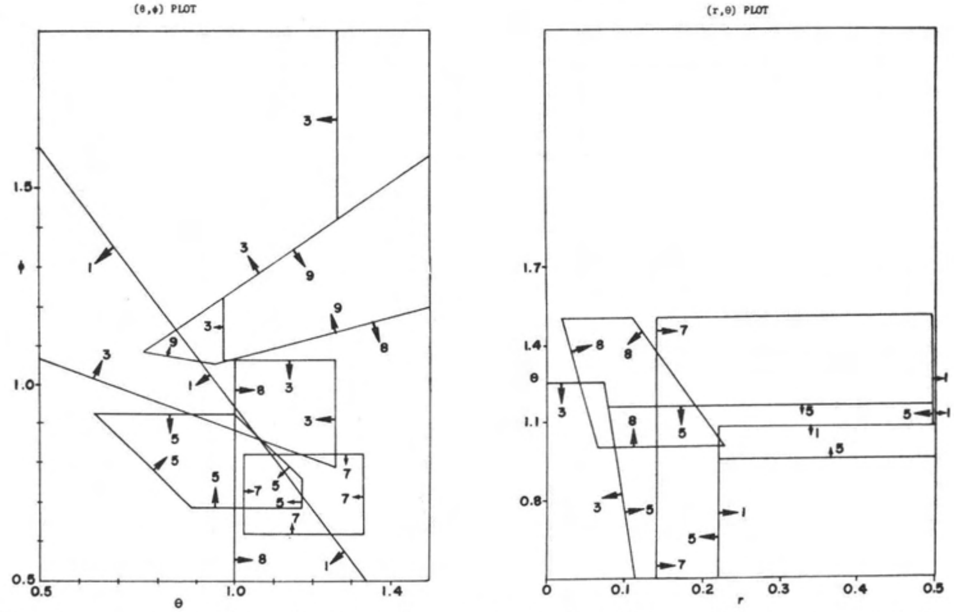

Fig. 4. Areas occupied by the object classes in (θ, ϕ) space (left), and (r, θ) space (right). The algorithms defining the space occupied by the object classes are given in Table 2.

(bright soil and brownish concrete). The regions of overlap are small and not statistically significant, as evidenced by the accuracy of the scene classifications listed in Table 3.

Results

A set of classification maps was generated for the five sites. An experienced photointerpreter generated maps from the color originals. The interpreter utilized low-altitude color imagery and ground truth data to insure that his manual classification of each scene area was accurate. The imagery was then calibrated to remove atmospheric and film effects, and the areas defined by the interpreter were measured by using the microdensitometer of the photointerpretation console. Multiple measurements were made within each area, with a conscious attempt made to measure points which had a different appearance.

The accuracies of the various map classifications are presented in Table 3. Table 3 contains a breakdown of the accuracy for each site and map type. The number of object areas classified on each map are also included. On the larger maps the poorest accuracy was 96 percent, the best 98 percent. On the smaller maps, the poorest accuracy was 86 percent, with this accuracy occurring on a homogeneous region with only 22 objects

Table 3. Classification Accuracies

Site	Large Area Map[1]		Small Area Maps[2]	
	Accuracy	No. of Areas	Accuracy	No. of Areas
1. Griffiss AFB	98%	168	95%	43
2. Verona, NY POL	96%	130	96%	45
3. Stockbridge SAM site	97%	169	86%	22
4. Schaghticoke Power Plant	98%	205	98%	48
5. Utica Railroad Yards	96%	210	*	*
Overall accuracy for all five scenes—97%				

[1] The large area maps were 10 km on side, mapped to 30 m resolution.
[2] The small area maps were 0.6 km on side, mapped to 5 m resolution.
* The resolution on the Utica imagery was too poor to permit mapping of the small area maps to the desired resolution.

(19 out of 22 objects correct).* Accuracies on more complex, smaller maps were 95 percent, 96 percent and 98 percent. The overall accuracy of the classification was 97 percent. There was no significant difference in classification accuracy between scenes. The Schaghticoke site, which was studied from 15,000 feet as opposed to 50,000 feet, was not classified to any greater degree of accuracy at the lower altitude. Most of the classification errors came from two categories: (1) the inability to distinguish concretes from certain bright soils; and (2) the confusion of turbid, green water with some cultivated fields.

The prime reason for successful implementation of the algorithms was the ability to account for atmospheric and film effects. The atmospheric effects on the Schaghticoke imagery were equivalent to a 6 percent reflector in red and green and a 10 percent reflector in the blue. For the higher altitude imagery, the effects were equivalent to about an 8 percent reflector in red and green and a 15 percent reflector in the blue. Soils and concretes usually have reflectances of about 20 percent, vegetation about 5 to 10 percent, and water about 5 percent. Thus, in many instances, the atmospheric effects can equal or exceed the signal from the object. Accurate photometric calibration is crucial for consistent classification.

Conclusions and Summary

The program has demonstrated that algorithms for classification of terrain features according to the categories metal, soil, pavement, cultivated fields, and vegetation can be developed for a color film mapping system. Classification accuracy from 1:100,000 scale imagery was about 97 percent.

The mapping categories used are not complex and correspond approximately to but a Level I land-use classification.[13] The algorithms are important, however, because they are independent of atmospheric and sensor conditions. Changes in atmospheric or sensor parameters usually require the time-consuming development of a training data set for each data collection mission; such training data are not necessary with these algorithms.

The algorithms which have been developed are, in addition, quite simple. In fact, little use has been made of the most elementary aspects of statistical decision theory and discriminant analysis in development of the algorithms. Further, the algorithms are based solely on the photometric properties of terrain features; textural and spatial parameters have been neglected in the algorithm development. We would therefore expect that the algorithms could be successfully extended to more complex classification schemes by incorporation of more powerful statistical techniques and spatial properties of the terrain features. A hierarchical classification scheme, such as Level II and III classification once Level I classification has been completed, should be feasible through extensions of the present approach.

Adoption of the present scheme of terrain classification based on reflectance values has an additional advantage over and above removing the requirement for development of training data. Reflectance data have been shown to be most useful in analyzing quality levels or conditions, such as water quality, vegetal vigor, and soil conditions.[1,3] Thus, once classification is accomplished with reflectance algorithms, quality analyses can be conducted by using the identical data base employed for terrain classification. A significant economy in overall cost and time of analyses could thus be realized.

Implementation of the terrain classification will require development of a digital image analysis system in which the photograph is automatically scanned and the image density values are converted first to reflectances and then to terrain classes by means of the algorithms which have been developed.

* The areas incorrectly classified were three shallow, greenish ponds which were classified as light vegetation (cultivated fields).

Acknowledgments

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