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Terrain and Look Angle Effects Upon Multispectral Scanner Response

The single element accounting for the most variation in response in the visible wavelength band was the sun-scanner look angle, while terrain elements account for appreciable variations in response in all wavelength bands.

Introduction

Sun angle and topographic influences upon multispectral scanner response interfere in computer-assisted classification of multispectral scanner (MSS) imagery. Researchers have employed various means to circumvent this problem: inclusion of several training fields of a cover type which are located in different terrain positions, use of preprocessing algorithms (Strahorn and Anuta, 1973), and taking ratios of two wavelengths bands (Vincent, 1972) in order to reduce or eliminate such effects. These methods have been moderately successful; however, computer-assisted classification of large areas has not been entirely satisfactory (West *et al.*, 1975).

Abstract: *Statistical analysis of airborne multispectral scanner (MSS) data of a pasture show that the effects of the sun-scanner look angle and terrain elements vary between spectral regions and wavelength bands. Shorter wavelength bands experienced the greatest influence, reflective infrared the least. Shorter wavelengths are most affected by the sun-scanner look angle alone.*

The variation in spectral reflectance as measured by a multispectral scanner from a single cover type recorded by a multispectral scanner can be caused by many factors. Among these are sun-scanner look angle, degree of homogeneity and density of the cover, surface texture, landscape position, slope direction and magnitude, and others. These factors are interrelated to varying degrees.

Laboratory and field experiments have demonstrated that spectral reflectance includes components of polarization and directional reflectance from natural surfaces (Coulson, 1966; Egbert and Ulaby, 1972; Eaton and Dirmhirn, 1979). These experiments also reveal that factors affecting reflectance vary from one cover type to another.

This study used statistical analysis to determine the extent of influence of various terrain elements and sun-scanner look angle upon airborne multispectral scanner response of a single cover type, a pasture. Details concerning the generation of digital elevation, slope magnitude, and slope direction, and summary tables of analyses are found in the appendix of this article.

Methods

Multispectral scanner data were collected by the Environmental Research Institute of Michigan (ERIM) over a test site in Augusta County, Virginia, on 8 April 1970 at an altitude of 600 metres (2,000 feet). Aerial photographs were taken the same day by the Virginia Highway Research Council. The test site was a pasture consisting of short grass over residual soil in one half of an irregular-shaped sinkhole in the center of the flight line. The pasture was selected for its uniform cover and near uniform tone on color aerial photography (Stohr and West, 1974). David Noble, Virginia Highway Research Council, confirmed the cover properties by field reconnaissance at the time of the overflight.

Local relief at the site was approximately 75

Photogrammetric Engineering and Remote Sensing,
Vol. 51, No. 2, February 1985, pp. 229-235.
0099-1112/85/5102-0229$02.25/0

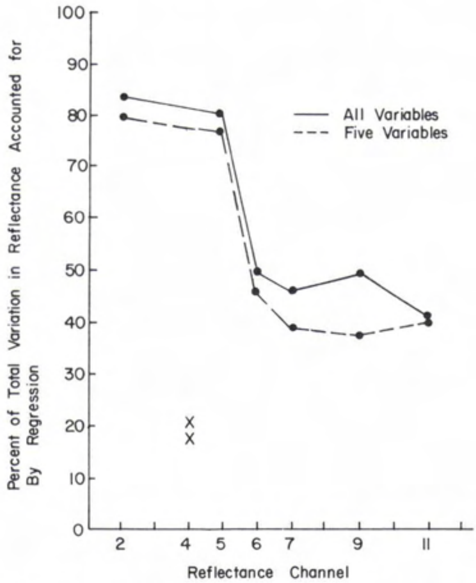

FIG. 1. Comparison of variation in response accounted for by regression in seven reflectance channels.

metres (250 feet) (see Figure 1). The instantaneous field-of-view of the scanner was about 2 metres (6 feet) in diameter. Data were collected in 12 spectral bands extending from 0.4 to 2.6 μm in analog form which was later digitized to provide an array with values supplied along equal ground distances.

Of the 1,208 pixels chosen from the test site for the statistical analysis, 908 pixels comprised the extremes of slope magnitude and 300 pixels were chosen by random selection from the more central portion of the distribution. This procedure insured that the effects of the extreme values would be considered without an undue increase in sample size.

Topographic (elevation) data were generated for each pixel of MSS data, i.e., a digital terrain model. Slope magnitude and slope direction were derived from the pixel elevations by vector addition and trigonometry. The two-dimensional angle between the sun and the sweeping multispectral scanner was calculated on a per-point basis (Stohr, 1974).

Contours and control points were digitized from a 7.5-minute series USGS quadrangle map with a 6 metre (20 foot) contour interval. Prior to overlaying the topographic data on the multispectral data, corrections for geometric distortion in the multispectral scanner data were made (Frederking *et al.*, 1974).

Statistical Analysis

The influence of terrain elements and sun-scanner look angle on spectral response was determined by stepwise multiple regression. High order models were developed by entering squares and cross products of individual variables in the linear equation. Regression equations were examined for six wavelength bands selected from the 12 available. The bands chosen were commonly used in computer-assisted classification of vegetation, soils, and land cover (see Table 1).

The relationship between the direction variable (0 to 180°) and the dummy variable (0 or 1) appeared at first to require that the two be entered into the regression equation together. However, experimentation showed that the combined influence of these two variables contributed little more than either variable alone. Consequently, all terrain variables were permitted to enter the regression independently.

Table 2 provides a list of variables considered in the statistical analysis. Per-point elevation information was not included in the analysis, as a previous determination showed that it provided no significant contribution beyond that supplied by the slope data.

Stepwise multiple regression used the variable additive method which incorporates variables into regression on the basis of partial correlation. The individual contribution of each variable which enters the model can be determined from the order

TABLE 1. MULTISPECTRAL DATA USED AS DEPENDENT VARIABLES IN THE REGRESSION ANALYSIS AND SUMMARY OF REGRESSION ANALYSIS

		Percent Spectral Variation Accounted For By		
Channel	Wavelength Band	Sun-Scanner Look Angle	Terrain Elements	Cross Products of Sun-Scanner Look Angle and Terrain Elements
1. Channel 2	0.46 to 0.48 μm	54.0	19.6	9.6
2. Channel 5	0.58 to 0.62 μm	45.0	16.0	19.0
3. Channel 6	0.62 to 0.66 μm	28.5	9.9	11.4
4. Channel 7	0.66 to 0.72 μm	24.0	8.7	9.3
5. Channel 9	0.80 to 1.00 μm	6.4	35.0	6.2
6. Channel 11	1.50 to 1.80 μm	1.3	14.6	27.8

TABLE 2. VARIABLES (ELEMENTS) CONSIDERED IN REGRESSION ANALYSIS RELATIVE TO TERRAIN EFFECTS

Dependent Variable

1. Reflectance measured by MSS for channel considered

Independent Variables

2. Slope magnitude, SM
3. Slope direction (0 to 180°), DIR
4. Sun-scanner look angle, S-SL
5. Slope direction dummy variable (0 or 1), DUM
6. Squared values, slope magnitude, $(SM)^2$
7. Squared values, slope direction, $(DIR)^2$
8. Squared values, sun scanner look angle, $(S\text{-}SL)^2$
9. Squared values, slope directions dummy variable, $(DUM)^2$
10. Cross products 2 and 3 above, SM × DIR
11. Cross products 2 and 4 above, SM × S-SL
12. Cross products 2 and 5 above, SM × DUM
13. Cross products 3 and 4 above, DIR × S-SL
14. Cross products 3 and 5 above, DIR × DUM
15. Cross products 4 and 5 above, S-SL × DUM

of entry and the amount of change on the spectral response (dependent variable). The model produced by the method has the form

$$Y_c = K + a_1X_1 + a_2X_2 + \ldots + a_mX_m,$$

where Y_c = predicted spectral response,
K = regression constant,
a = partial regression coefficient, and
X = independent variable.

The summary tables of analysis found in the appendix show step number, variable entered, multiple R squared, and increase in the R squared value. The multiple R squared (RSQ) indicates the cumulative percentage of variation in the dependent variable. The increase in multiple R squared is the percentage of variation accounted for by an individual variable.

RESULTS

Statistical analysis shows that spectral response was influenced by terrain and sun-scanner look angle. The summary tables (Tables 3 through 8) of analyses for channels 2, 5, 6, 7, 9, and 11 show:

- The total variation of spectral response accounted for by all variables in regression ranged from 42 percent to 83 percent. However, variables did not enter in the same order for all wave-length bands. The greatest consistency of entry was for the visible wavelengths. The total variation of response accounted for by all variables and the first five variables decreased with increasing wavelength (shown graphically in Figure 2). This is consistent with results of laboratory studies of a grass turf by Coulson (1966).
- The single element accounting for the most variation in response was the sun-scanner look angle with 54, 45, 28, and 24 percent of total spectral response variation, respectively, for visible wavelength band (channels 2, 5, 6, and 7). However, the sun-scanner look angle accounted for a very small variation in the infrared response, i.e., 6.4 percent for band 0.80 to 1.00 μm and 1.3 percent for band 1.50 to 1.80 μm.
- Terrain elements (slope magnitude, direction, and their cross products) account for appreciable variations in response in all wavelength bands. As the visible wavelengths increase, the influence of terrain elements decreases. This does not follow for the infrared wavelengths, which are far more influenced by terrain elements than by the sun-scanner look angle (see Table 1).
- Cross products of terrain elements and the sun-scanner look angle account for about as much visible spectral variation as the terrain variables alone, but the cross product influence for infrared channels is mixed (see Table 1).
- The first three parameters to enter into the regression equations of channels 5, 6, and 7 were sun-scanner look angle followed by a combination of slope magnitude and sun-scanner look angle, and then slope magnitude alone. These three elements account for 70, 44, and 37 percent of the total spec-

TABLE 3. CHANNEL 2 (0.46 TO 0.48 μm) SUMMARY TABLE OF ANALYSIS

Step Number	Variable Entered	Multiple RSQ	Increase in RSQ	Name of Element Entered
1	8	0.5347	0.5347	$(S\text{-}SL)^2$
2	12	0.6501	0.1153	SM × DUM
3	7	0.6820	0.0319	$(DIR)^2$
4	15	0.7674	0.0854	S-SL × DUM
5	14	0.7978	0.0304	DIR × DUM
6	13	0.8024	0.0046	DIR × S-SL
7	10	0.8070	0.0046	SM × DIR
8	6	0.8145	0.0075	$(SM)^2$
9	11	0.8209	0.0064	SM × S-SL
10	2	0.8268	0.0060	SM
11	4	0.8340	0.0072	S-SL
12	3	0.8343	0.0003	DIR

TABLE 4. CHANNEL 5 (0.58 TO 0.62 μm) SUMMARY TABLE OF ANALYSIS

Step Number	Variable Entered	Multiple RSQ	Increase in RSQ	Name of Element Entered
1	8	0.4543	0.4543	$(S\text{-}SL)^2$
2	11	0.6137	0.1594	SM × S-SL
3	2	0.7006	0.0869	SM
4	15	0.7312	0.0307	S-SL × DUM
5	14	0.7719	0.0407	DIR × DUM
6	5	0.7975	0.0256	DUM
7	10	0.8028	0.0053	SM × DIR
8	13	0.8037	0.0008	DIR × S-SL
9	6	0.8041	0.0004	$(SM)^2$
10	7	0.8044	0.0004	$(DIR)^2$
11	12	0.8045	0.0000	SM × DUM

TABLE 5. CHANNEL 6 (0.62 TO 0.66 μm) SUMMARY TABLE OF ANALYSIS

Step Number	Variable Entered	Multiple RSQ	Increase in RSQ	Name of Element Entered
1	8	0.2848	0.2848	$(S\text{-}SL)^2$
2	11	0.3819	0.0970	SM × S-SL
3	2	0.4379	0.0561	SM
4	15	0.4540	0.0161	S-SL × DUM
5	14	0.4745	0.0205	DIR × DUM
6	5	0.4918	0.0173	DUM
7	10	0.4963	0.0045	SM × DIR
8	6	0.4971	0.0008	$(SM)^2$
9	13	0.4978	0.0007	DIR × S-SL
10	7	0.4979	0.0000	$(DIR)^2$
11	12	0.4979	0.0000	SM × DUM

TABLE 6. CHANNEL 7 (0.66 TO 0.72 μm) SUMMARY TABLE OF ANALYSIS

Step Number	Variable Entered	Multiple RSQ	Increase in RSQ	Name of Element Entered
1	8	0.2417	0.2417	$(S\text{-}SL)^2$
2	11	0.3218	0.0801	SM × S-SL
3	2	0.3703	0.0485	SM
4	15	0.3827	0.0124	S-SL × DUM
5	5	0.4061	0.0234	DUM
6	12	0.4165	0.0105	SM × DUM
7	14	0.4200	0.0035	DIR × DUM
8	6	0.4204	0.0004	$(SM)^2$
9	10	0.4208	0.0004	SM × DIR
10	13	0.4213	0.0004	DIR × S-SL
11	7	0.4213	0.0000	$(DIR)^2$

tral response variation for channels 5, 6, and 7, respectively. The slope direction parameters (variables 3, 5, and 14 in Table 2) accounted for less than 12 percent, and in half of the channels less than 5 percent of the total spectral response variation was contributed by terrain elements. This agrees with the findings by Egbert and Ulaby (1972) that reflectance variations due to azimuth direction were reduced when the solar elevation angle exceeds 35° (the value for this study was 58°).

DISCUSSION

Some of the variation in MSS response accounted for by the sun-scanner look angle may be attributable to atmospheric scattering or directional reflectance. This is a likely interpretation as the greatest variations in response were accounted for by the sun-scanner look angle for shorter wavelength bands; the least variation occurred for the reflective infrared bands.

TABLE 7. CHANNEL 9 (0.80 TO 1.00 μm) SUMMARY TABLE OF ANALYSIS

Step Number	Variable Entered	Multiple RSQ	Increase in RSQ	Name of Element Entered
1	12	0.2356	0.2356	SM × DUM
2	11	0.2864	0.0508	SM × S-SL
3	6	0.3283	0.0420	$(SM)^2$
4	15	0.3375	0.0091	S-SL × DUM
5	14	0.3645	0.0270	DIR × DUM
6	4	0.4279	0.0635	S-SL
7	5	0.4639	0.0360	DUM
8	2	0.4680	0.0041	SM
9	7	0.4717	0.0037	$(DIR)^2$
10	13	0.4734	0.0017	DIR × S-SL
11	10	0.4752	0.0018	SM × DIR

TABLE 8. CHANNEL 11 (1.50 TO 1.80 μm) SUMMARY TABLE OF ANALYSIS

Step Number	Variable Entered	Multiple RSQ	Increase in RSQ	Name of Elements Entered
1	15	0.2673	0.2673	S-SL × DUM
2	14	0.3619	0.0945	DIR × DUM
3	8	0.3746	0.0127	$(S\text{-}SL)^2$
4	6	0.3885	0.0140	$(SM)^2$
5	5	0.4019	0.0134	DUM
6	11	0.4085	0.0066	SM × S-SL
7	13	0.4129	0.0044	DIR × S-SL
8	10	0.4200	0.0071	SM × DIR
9	12	0.4236	0.0036	SM × DUM
10	7	0.4238	0.0002	$(DIR)^2$
11	2	0.4240	0.0002	SM

The inconsistency of entry of the variables is difficult to interpret. Entry of variables in the visible wavelength region is generally consistent, and the elements or combinations are similar between bands. However, entry of variables for the blue band (channel 2) differs from the other visible bands.

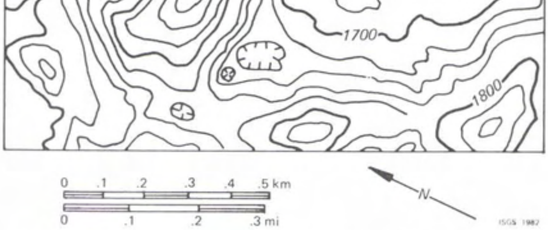

FIG. 2. Topographic map of the terrain effects in the study area at Stuarts Draft, Virginia. Contours are in feet.

The sequence of variables entering the regression equation differs markedly between the two infrared bands; the slope direction dummy variable (defined in the appendix) in conjunction with either slope magnitude in channel 9 or the sun-scanner look angle in channel 11 accounts for the greatest individual variation in response. Only slope magnitude (variable 6) and the cross product of slope direction and the dummy variable (variable 14) accounted for appreciable variation in spectral response for both infrared channels. The cross product of the sun-scanner look angle with the dummy variable had a high correlation with spectra from both infrared channels, but varied in the amount of spectral variation accounted for by that variable: 27 percent in channel 11 (0.81-1.00 μm) and less than 1 percent in channel 15 (1.50-1.80 μm).

STUDY LIMITATIONS

The reader will note that topographic data were distorted to fit the MSS data, although the study site is near the center of the flight line where geometric distortions are minimal. Furthermore, the effects of moisture changes, soil types, and variation in plant vigor of the improved pasture were not taken into account.

ACKNOWLEDGMENTS

The authors wish to thank the Laboratory for Applications of Remote Sensing (LARS), Purdue University, West Lafayette, Indiana for their technical assistance and, in particular, Phil Swain, Paul Anuta, Virgil Anderson, James Baker, and Barbara Davis. This work was supported by funding from the Federal Highway Administration, U.S. Department of Transportation Contract DOT-FH-7565. David R. Nobel of the Virginia Highway Research Council provided aerial photographs and field assistance for which the authors are indebted. Mary McGuire and Linda Cunningham typed the several drafts of the manuscript.

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(Received 23 March 1982; revised and accepted 30 October 1984)

APPENDIX

GENERATION OF TERRAIN DATA

The distortion of the topographic data to fit the scanner data was accomplished by the use of a computer program developed by Baker and Mikhail (1975). The program interpolates between the digitized contour values to complete the array of elevation data, generating the digital terrain model which is corrected for geometric distortions (Stohr, 1974; Frederking *et al.*, 1974). The digital terrain model becomes an "extra" channel of pixel elevations in addition to the spectral data. Magnitude and

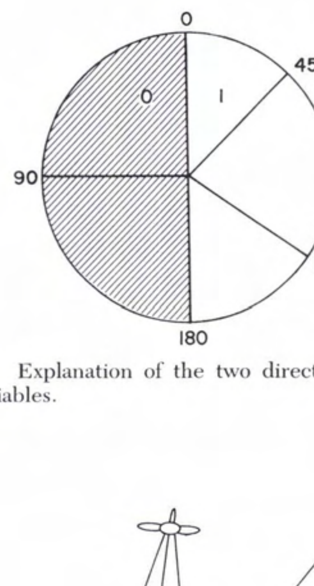

FIG. A1. Explanation of the two direction of slope of slope variables.

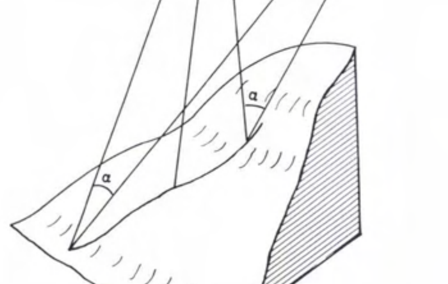

FIG. A2. Diagrammatic representation of the effects of sun-scanner look angle and of magnitude and direction of slope.

direction of slope then were calculated from the per-point elevations by vector addition and trigonometry.

Slope direction poses a special problem because azimuths do not form a continuous function. Azimuth values range from 0 to 360°, but because of the cyclic nature involved, 360° for example is the same as 0°, yet these would be considered end members in a linear statistical analysis such as we used.

This difficulty was overcome by dividing azimuths into the two hemispheres with a symmetrical relationship between them (see Figure A1). A dummy variable (with values of 0 or 1) was used to identify the hemisphere to which the slope direction belongs. Thus, slope direction is indicated by use of two variables, the first to indicate the angle difference measured from north and the second to show whether that direction is clockwise or counterclockwise.

One of the variables included, sun-scanner look angle, is not a terrain element *per se*. This variable, α, is a two-dimensional angle between the sun and the scanner lens (see Figure A2).