# Using Multispectral Video Imagery for Detecting Soil Surface Conditions

*J.H. Everitt, D. E. Escobar, M. A. Alaniz,* and *M. R. Davis*
USDA Agricultural Research Service, Remote Sensing Research Unit, P. O. Box 267, Weslaco, TX 78596

ABSTRACT: Multispectral video imagery was evaluated in two experiments for its ability to discriminate among a variety of soil surface conditions. Experiments were conducted with pans having five soil surface treatments [(1) wet smooth, (2) disked wet, (3) disked dry, (4) crusted dry, and (5) smooth dry surfaces] and field plots with three soil surface treatments [(1) crusted dry, (2) disked dry, and (3) wet surfaces]. Seven multispectral images were acquired of each experiment by equipping four black-and-white video cameras [two of them visible (0.40 to 0.70 μm), one visible/near-infrared (NIR) (0.40 to 1.1 μm), and one visible/infrared (0.40 to 2.4 μm) sensitive] with visible, NIR, and mid-infrared (MIR) filters. The seven filters used were green (0.516 to 0.524 μm), yellow-green (0.543 to 0.552 μm), orange (0.586 to 0.595 μm), red (0.644 to 0.656 μm), deep dark red (0.712 to 0.725 μm), NIR (0.815 to 0.827 μm), and MIR (1.45 to 2.0 μm). Digital video data were obtained from the plots within each image. Spectroradiometric reflectance measurements were made on the plots at approximately the same waveband intervals that were used to obtain video images. Digital data from all seven video bands were highly correlated ($p = 0.01$) with reflectance data from corresponding bands for both experiments. For the pan experiment, the best correlations (all $r$'s = 0.91) between digital video and reflectance data were obtained for the green, red, and orange wavebands. For the field experiment, the best correlation ($r = 0.98$) between digital video and reflectance data was obtained for the MIR waveband. Surface-soil water content was significantly correlated to digital video data from most wavebands in both experiments, but the best correlations were obtained between water content and MIR digital video data in both experiments. These findings indicate that multispectral video imagery can be used successfully to differentiate among various soil surface conditions.

## INTRODUCTION

WITHIN THE PAST FEW YEARS, video cameras and recording systems have been used for remote sensing applications because of the immediately useful information they provide (Vlcek, 1983; Meisner and Lindstrom, 1985; Nixon *et al.*, 1985). Although video has proven useful for a variety of natural resource applications, most studies have been conducted on vegetation assessment (Edwards, 1982; Manzer and Cooper, 1982; Escobar *et al.*, 1983; Nixon *et al.*, 1984; Everitt and Nixon, 1985; Everitt *et al.*, 1986; King *et al.*, 1987; Lulla *et al.*, 1987; Lusch and Sapio, 1987).

Recent studies have shown that video imagery has potential for detecting soil surface conditions (Everitt *et al.*, 1987; Nixon *et al.*, 1987). However, little other information is available using video for assessing soils. The objective of this study was to evaluate multispectral video for differentiating among a variety of soil surface conditions by relating digital video data to spectroradiometric reflectance data and soil water content.

## MATERIAL AND METHODS

Research was conducted at the USDA-ARS facilities at Weslaco, Texas. Two experiments were made to evaluate video for differentiating soil surface conditions. Hidalgo fine sandy loam soil (fine-loamy, mixed, hyperthermic, Typic Calciustolls) was used for both experiments. The first experiment was done using large stainless steel pans [66 cm (length) by 56 cm (width) by 8 cm (deep)] filled with soil. Black tape was placed around the upper edges of the pans to eliminate the steel reflectance. A randomized complete block design was used with four replications of five soil surface treatments: (1) smooth wet surface, (2) disked wet surface, (3) disked dry surface, (4) crusted dry surface, and (5) smooth dry surface. Soil was collected in the field from the surface 20 cm, transported to the laboratory, and air-dried. The soil had been previously disked and was comprised of variable size (1 to 7 cm) clods. About one-fifth of the soil was set aside and the remainder was ground and passed through wire screen sieves that had 2-mm opening. Pans designated as treatments 1, 2, 4, and 5 were overfilled with the sieved air-dry soil, and the excess soil was removed with a straight edge in contact with the top of the pans. Pans designated as treatment 3 (disked dry) were filled to the top with the disked soil that was set aside. The pans were then placed in a greenhouse. Pans designated as treatment 4 (dry crusted soil) were wetted with distilled water (4 litres) and allowed to dry for about two weeks to form a dry crusted surface. Pans designated as treatments 1 (smooth wet surface) and 2 (disked wet surface) were wetted with 4 litres of water on the day prior to the experiment. On the day of experiment, the pans were removed from the greenhouse and placed on a black background in full sunlight. The pans were handled carefully to prevent disturbing the surfaces. Pans designated as treatment 2 (disked wet surface) had their surfaces disturbed with a hand rake to simulate disking immediately prior to conducting the experiment. The treatment 1 (smooth wet surface) pans were wetted with 1 litre of water immediately prior to conducting the experiment.

The second experiment was conducted using large bare soil plots (9.1 m by 9.1 m). A randomized complete block design was used with four replications of three soil surface treatments: (1) crusted dry, (2) disked dry, and (3) wet surface. The area had received rain a few days prior to the experiment and, consequently, the soil had a dry crusted surface. Thus, plots designated as treatment 1 (crusted dry surface) did not have to have a treatment applied. Plots designated as treatment 2 (disked dry surface) had their surfaces disked with a small garden rototiller. Plots designated as treatment 3 (wet surface) were flood irrigated with approximately 12.5 cm of water two days prior to the experiment. Large borders were built around the plots to prevent water from seeping into adjacent plots. No water remained on the plots when the study was conducted. Also, no rainfall occurred during the study period.

Video imagery of the experiment conducted with the pans was obtained with a MII[1,2] 2500 video camera from a Truco aerial

[1]Trade names are included for the benefit of the readers and do not imply an endorsement of or a preference for the product listed by the U.S. Department of Agriculture.

[2]MII Inc., P.O. Box 395, Birdsboro, PA 19508.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 55, No. 4, April 1989, pp. 467–471.

0099-1112/89/5504–467$02.25/0

TABLE 1. FILTERS USED ON VIDEO CAMERAS.

| Filter | Sensitive Waveband (μm) |
|---|---|
| Green | 0.516 – 0.524 |
| Yellow-green | 0.543 – 0.552 |
| Orange | 0.586 – 0.595 |
| Red | 0.644 – 0.656 |
| Deep dark red | 0.712 – 0.725 |
| Near-infrared | 0.815 – 0.827 |
| Mid-infrared | 1.45 – 2.0 |

lift ("cherry picker") placed 12 m above the pans. The camera had a specially designed lead oxide (PbO) - lead sulfide (PbS) camera tube (1.0 in. format) to give visible/infrared light (0.4 to 2.4 μm) sensitivity (Everitt *et al.*, 1987). Imagery was obtained with 7 filters (Table 1) between 1400 and 1430 hours under sunny conditions. The camera lens focal length (zoom) was set at 40 mm. The video signal was digitized directly into an $I^2S$ image processor with a 512 by 512 line digitizing board to improve the resolution of the imagery over that obtained from the typical recorder. The images were stored on a disc to avoid data loss.

Airborne video imagery of the large field plot experiment was acquired with four video cameras. Simultaneous imagery was obtained with the MII camera and three Sony AVC-3450 video cameras (Nixon *et al.*, 1985). Imagery was recorded on four Sony SLO-340 video cassette recorder/players (1/2 in. Beta format). The Sony cameras had 0.7-in. format camera tubes. One of the Sony cameras was modified with an RCA Ultricon (TM) 4875/U camera tube to give visible/near-infrared (NIR) light (0.4 to 1.1 μm) sensitivity. The other two Sony cameras had only visible light (0.40 to 0.70 μm) sensitivity. Imagery of the plots was recorded with the same filters used in the experiment conducted with the pans (Table 1). The mid-infrared (MIR) filter was used on the MII camera, whereas, the NIR (0.815 to 0.827 μm) and deep dark red (0.712 to 0.725 μm) filters were used on the visible/NIR sensitive camera. The other four visible filters were used with the visible sensitive cameras. All camera zoom lenses were set at a focal length of 40 mm. Imagery was obtained at an altitude of 450 m using a Cessna 182 airplane. Multiple passes were made over the plots to obtain imagery with the seven filters. The pilot slowed the plane to 70 knots when acquiring imagery to avoid image lag, which is a problem with the MII camera (Everitt *et al.*, 1987). Imagery was taken between 1300 and 1400 hours under sunny conditions.

Airborne video scenes acquired of the large field plots with each filter (Table 1) were digitally entered into an $I^2S$ image processor using a SLO-383 Betamax I video cassette recorder/player that was interfaced to the image processor's video digitizer through an Edutron time-base corrector. Images were stored on disc. Image processor functions were used to acquire digital count data from each whole plot.

Ground reference data were collected from each experiment at the time imagery was obtained. Reflectance measurements were made on soil using an Exotech Model 20 spectroradiometer (Leamer *et al.*, 1973). Reflected radiation was measured at 0.05-μm increments over the 0.45- to 2.45-μm spectral region with a sensor that had a 15° field-of-view. Measurements were made from the "cherry picker" placed 3.0 m (0.75 $m^2$ ground area) above such field plot and 1.0 m (0.25 $m^2$ ground area) above each pan. Two measurements were made from each plot and averaged. Duplicate soil moisture samples were also collected from the upper 0.5 cm of soil from each plot. Samples were placed in air-tight metal cans and water content was determined on an oven dry weight basis (68°C for 96 hours).

Correlation and regression analyses were conducted for reflectance measurements and surface-soil water content data versus video digital count data obtained from the individual plots (Steel and Torrie, 1980). Reflectance data were calculated from the wavelengths that most closely corresponded to the filters used to acquire video images.

## RESULTS AND DISCUSSION

The regression equations and simple correlation ($r$) coefficients for reflectance measurements and surface-soil water content with digital video data for the pan soil surface experiment are given in Table 2. All $r$ coefficients were highly statistically significant ($p = 0.01$). Correlations between reflectance measurements and digital video data were linear, whereas those between soil water content and digital video data were nonlinear (exponential). Reflectance measurements were directly related to video data. Conversely, soil water content was inversely related to video data. For reflectance versus digital video, the best $r$ values were obtained for the correlations of green, orange, and red reflectance with green, orange, and red digital video data, respectively. The best correlation between soil water content and digital video data was obtained for the MIR waveband. This is in agreement with previous research showing a close relationship between MIR reflectance (1.45 to 2.0 μm) mea-

TABLE 2. REGRESSION EQUATIONS AND CORRELATION COEFFICIENTS FOR CORRELATIONS OF GROUND REFLECTANCE MEASUREMENTS FROM SEVEN WAVEBAND INTERVALS AND SOIL SURFACE WATER CONTENT WITH DIGITAL VIDEO DATA FROM CORRESPONDING WAVEBAND INTERVALS OBTAINED FROM PANS WITH FIVE SOIL SURFACE TREATMENTS.

| Dependent Variable | Independent Variable | Equation | $r$ |
|---|---|---|---|
| Green reflectance | green video | $y = 10.35 + 9.06X$ | 0.91** |
| Yellow-green reflectance | yellow-green video | $y = 5.81 + 7.98X$ | 0.90** |
| Orange reflectance | orange video | $y = 6.82 + 7.05X$ | 0.91** |
| Red reflectance | red video | $y = 1.61 + 6.36X$ | 0.91** |
| Deep dark red reflectance | deep dark red video | $y = 0.92 + 5.42X$ | 0.88** |
| Near-infrared reflectance | near-infrared video | $y = -5.48 + 2.60X$ | 0.87** |
| Mid-infrared reflectance | mid-infrared video | $y = -13.41 + 3.13X$ | 0.84** |
| Water content | green video | $y = 113.17X^{-0.213}$ | −0.87** |
| Water content | yellow-green video | $y = 110.74X^{-0.220}$ | −0.87** |
| Water content | orange video | $y = 106.94X^{-0.221}$ | −0.88** |
| Water content | red video | $y = 102.28X^{-0.225}$ | −0.88** |
| Water content | deep dark red video | $y = 94.02X^{-0.290}$ | −0.88** |
| Water content | near-infrared video | $y = 20.36X^{-0.176}$ | −0.81** |
| Water content | mid-infrared video | $y = 97.00X^{-0.30}$[illegible] | −0.91** |

**Significant at 0.01 probability level.

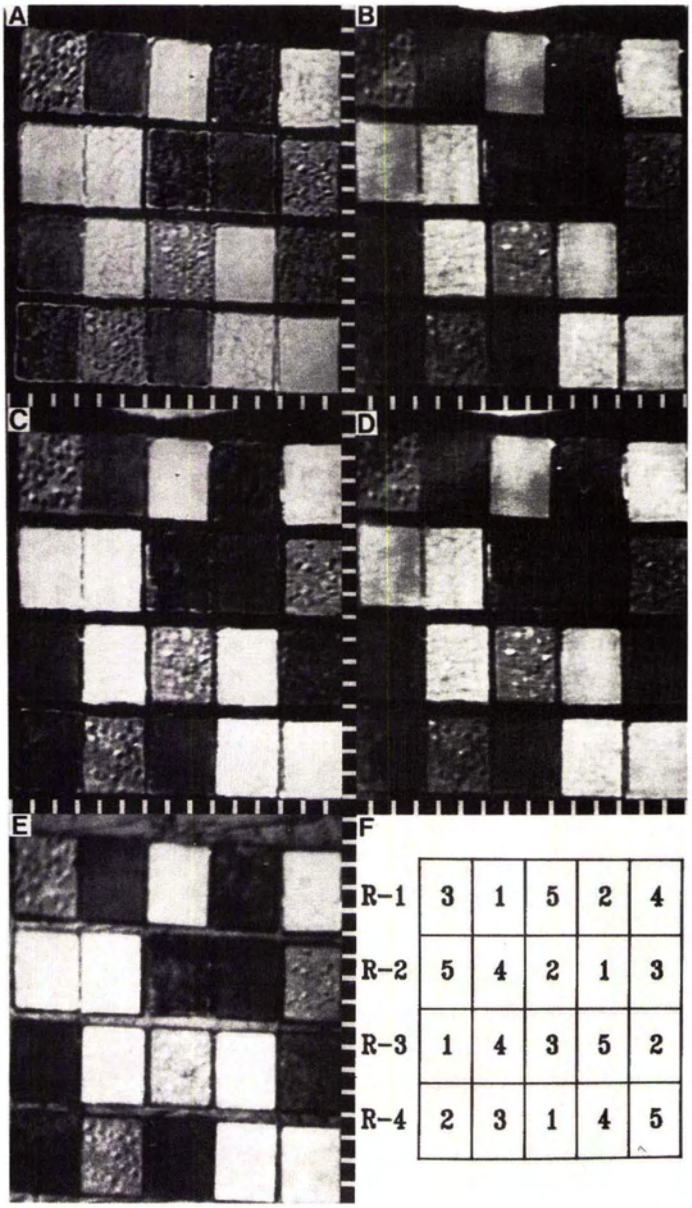


FIG. 1. Green (A), red (B), deep dark red (C), NIR (D), and MIR (E) video images and plot diagram (F) of pans with five soil surface treatments [(1) smooth wet, (2) disked wet, (3) disked dry, (4) crusted dry, and (5) smooth dry].

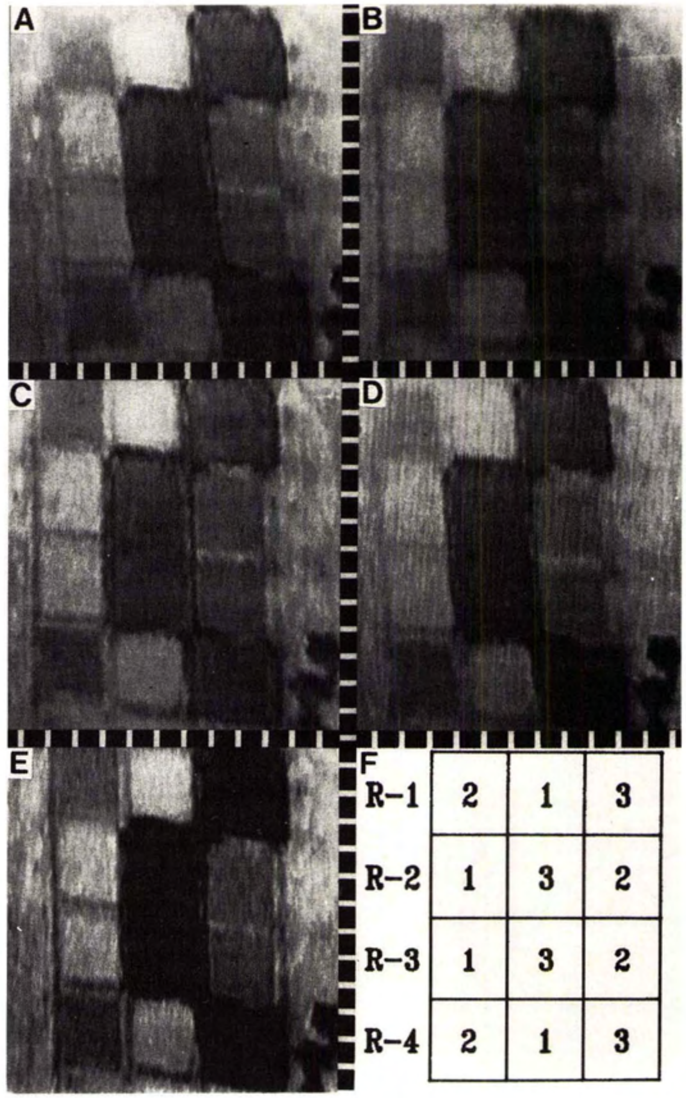


FIG. 2. Yellow-green (A), orange (B), red (C), deep dark red (D), and MIR (E) aerial video images and plot diagram (F) of field plots with three soil surface treatments [(1) crusted dry, (2) disked dry, and (3) wet].

surements and soil water content (Gates, 1965; Bowers and Hanks, 1965; Skidmore *et al.*, 1975).

Figure 1 (A-F) shows green, red, deep dark red, NIR, and MIR video images, and the plot diagram, respectively, of the pan soil surface experiment. In the green image [Figure 1 (A)], the smooth wet (1) plots had a dark gray tone while the disked wet (2) plots had a variable image response made up of light gray, dark gray, and almost black tones. The disked dry (3) plots had a light gray tone, whereas the crusted dry (4) and smooth dry (5) plots had a whitish tonal response.

The tonal responses of the five treatments within the red, deep dark red, NIR, and MIR images (Figure 1 (B, C, D, and E, respectively) were similar to those within the green image, except the smooth wet and disked wet treatment plots had slightly darker tonal responses in these images than in the green image. The tonal responses of the various treatment plots in the yellow-green image (not shown) were similar to those within the green image, whereas treatment differences within the orange image (not shown) were comparable to those in the red, deep dark red, NIR, and MIR images. Apparently, the surface soil water content (Table 4) of the smooth wet and disked wet plots was not high enough to give these plots a darker tonal response within the MIR image than in the images acquired with the visible/NIR filters. Everitt *et al.* (1987) showed that MIR video imagery could be used to distinguish wet soil from other land-use features, but their findings were based on a field having standing water and completely saturated soil probably at field capacity.

The regression equations and simple correlation coefficients for reflectance measurements and surface-soil water content with digital video data for the field soil surface experiment are presented in Table 3. All $r$ coefficients obtained between reflectance measurements and digital video data were highly statistically significant ($p = 0.01$), ranging from 0.91 to 0.98. The best correlation was obtained between MIR reflectance and MIR digital video data. Correlations between reflectance measurements and digital video data were linear and the two parameters were

TABLE 3. REGRESSION EQUATIONS AND CORRELATION COEFFICIENTS FOR CORRELATIONS OF GROUND REFLECTANCE MEASUREMENTS FROM SEVEN WAVEBAND INTERVALS AND SOIL SURFACE WATER CONTENT WITH DIGITAL VIDEO DATA FROM CORRESPONDING WAVEBAND INTERVALS OBTAINED FROM FIELD PLOTS WITH THREE SOIL SURFACE TREATMENTS.

| Dependent Variable | Independent Variable | Equation | $r$ |
|---|---|---|---|
| Green reflectance | green video | $y = 67.83 + 3.82X$ | 0.93** |
| Yellow-green reflectance | yellow-green video | $y = 57.79 + 3.75X$ | 0.91** |
| Orange reflectance | orange video | $y = 71.19 + 3.45X$ | 0.95** |
| Red reflectance | red video | $y = 61.24 + 4.37X$ | 0.96** |
| Deep dark red reflectance | deep dark red video | $y = 54.98 + 2.90X$ | 0.97** |
| Near-infrared reflectance | near-infrared video | $y = 3.88 + 2.85X$ | 0.97** |
| Mid-infrared reflectance | mid-infrared video | $y = 30.32 + 3.41X$ | 0.98** |
| Water content | green video | $y = 109.66X^{-0.041}$ | −0.64N.S. |
| Water content | yellow-green video | $y = 106.42X^{-0.057}$ | −0.75* |
| Water content | orange video | $y = 119.01X^{-0.044}$ | −0.68* |
| Water content | red video | $y = 127.10X^{-0.055}$ | −0.66N.S. |
| Water content | deep dark red video | $y = 104.21X^{-0.063}$ | −0.77* |
| Water content | near-infrared video | $y = 60.88X^{-0.082}$ | −0.62N.S. |
| Water content | mid-infrared video | $y = 136.03X^{-0.111}$ | −0.87** |

*Significant at 0.05 probability level.
**Significant at 0.01 probability level.
N.S. = not significant.

TABLE 4. MEAN WATER CONTENT OF VARIOUS SOIL SURFACE TREATMENTS FROM PAN AND FIELD EXPERIMENTS.

| Experiments and Treatments | Water Content (%) |
|---|---|
| *Pan Experiment* | |
| Smooth wet surface | 20.3 ± 1.1[a] |
| Disked wet surface | 11.4 ± 1.1 |
| Disked dry surface | 1.9 ± 0.3 |
| Crusted dry surface | 1.5 ± 0.5 |
| Smooth dry surface | 1.9 ± 0.4 |
| *Field Experiment* | |
| Crusted dry surface | 1.1 ± 0.2 |
| Disked dry surface | 1.0 ± 0.1 |
| Wet surface | 30.2 ± 1.9 |

[a]Standard deviation

directly related. For correlations (all nonlinear) between soil water content and digital video data, only the $r$ values obtained for water content versus yellow-green, orange, deep dark red, and MIR digital video were statistically significant. Soil water content was inversely related to digital video data. The highest $r$ coefficient (−0.87) was obtained between soil water content and MIR digital video data.

The yellow-green, orange, red, deep dark red, and MIR video images, and plot diagram of the field plot soil surface experiment are shown in Figure 2 (A, B, C, D, E, and F, respectively). Differences among the three soil surface treatments were most apparent in the MIR video image [Figure 2 (E)] where crusted dry (1) plots had a whitish-gray tone, disked dry (2) plots had a gray tone, and wet (3) plots had a black tone. The black tone of the wet plots within the MIR image was attributed to their high surface-soil water content (30.2 percent) (Table 4). Soil within the wet plots was nearly saturated; consequently, they absorbed a large percentage of the MIR radiation (Bowers and Hanks, 1965; Skidmore *et al.*, 1975). These findings are in agreement with those of Everitt *et al.* (1987).

The yellow-green, orange, red, and deep dark red images (Figure 2 - A, B, C, and D, respectively), and the green and NIR images (not shown) were very similar. The three surface treatments could be separated within these images, but their tonal differences were not as distinct as within the MIR image. Within these images, the wet plots had a dark gray image tone that more closely resembled the gray tone of the dry disked plots.

## SUMMARY AND CONCLUSIONS

Results showed that video imagery can be used to distinguish among a variety of soil surface conditions. We found that digital video data obtained from seven multispectral (green, yellow-green, orange, red, deep dark red, NIR, and MIR wavebands) video images of soil surface experiments conducted with pans and large field plots were significantly ($p = 0.01$) correlated to reflectance measurements made on the plots at corresponding waveband intervals. For the pan soil surface experiment (treatments: smooth wet, disked wet, disked dry, crusted dry, and smooth dry), the best correlations between digital video and reflectance data were obtained for the green, red, and orange wavebands. However, in the field soil surface study (treatments: crusted dry, disked dry, and wet), the best correlation between digital video and reflectance data was obtained for the MIR waveband. Surface-soil water content data were significantly correlated to digital video data at all seven wavebands in the pan experiment and to yellow-green, orange, deep dark red, and MIR digital video data in the field experiment, but the best correlations were obtained between water content and MIR digital video data in both studies. These findings should be useful to soil scientists and consultants interested in using remote sensing techniques for irrigation management.

## ACKNOWLEDGMENTS

Special thanks are extended to Juan Noriega and Rick Villarreal for their assistance in the field and laboratory.

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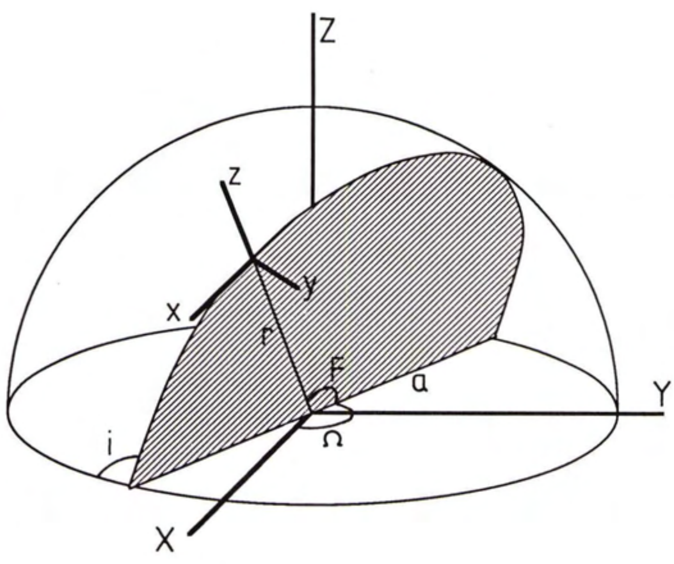
(Received 26 September 1988; accepted 17 November 1988; revised 8 December 1988)




## Erratum

In the paper, "Topographic Mapping from SPOT Imagery," by D. J. Gugan and I. J. Dowman (*PE&RS*, October 1988, pages 1409–1414), the notation was inadvertantly left off of Figure 1. The correct Figure 1 is shown herein.