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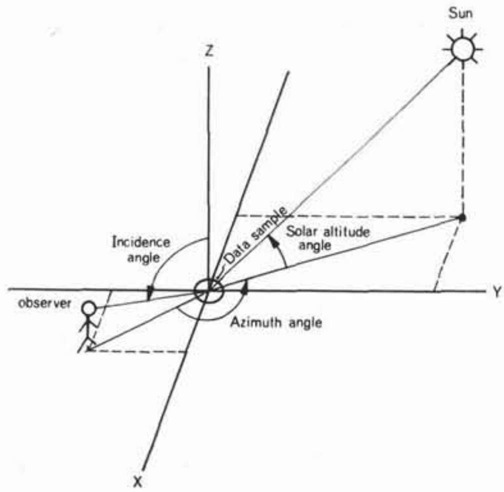

FIG. 1. Geometry of the experiment on spectral reflectivity and definitions of the angles of interest.

Effect of Angles on Reflectivity

Spectral reflectivity curves obtained in the field can aid in the interpretation of multiband images and in the planning of remote sensing missions.

INTRODUCTION

THIS INVESTIGATION developed and tested a practical and inexpensive technique for obtaining spectral reflectivity curves in the visible and near-infrared regions of the electromagnetic spectrum for any desired type of target. This technique also yields reflectivity information about the target as a function of sun altitude angle, incidence look angle, and the azimuth angle between sun, data sample, and observer (Figure 1). Both the spectral reflectivity and its angular dependence can be very useful in planning remote sensing missions (aircraft or satellite) with multiband photography.

If a mission is aimed at mapping a specific type of target, for example, the optimum choice of filters will depend not only on this target's spectral characteristics but also on the background's spectral properties. However, these data are not generally available for target background combinations. The results of this test may be used to determine not only optimum spectral bands but also whether a multiband mission is even feasible for detecting a given type of object. In addition, the time of day for the flight and possibly the direction of the flight line may be determined from information about the various angles versus reflectivity. This test is particularly important if flights are being planned with low-resolution photography such as high-altitude or space photography, or if automatic data processing of the resultant imagery is desired. For conventional photo-interpretive techniques, texture and shape play an important role in detectability and identification of objects. However, low-resolution images and most automatic data processors at the present time rely only on image-density data.

During this investigation multispectral

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reflectivity measurements were employed in conjunction with a study which mapped roads from color space photographs (Simonett, et al., 1969). Also an experiment was conducted under controlled conditions to determine the exact dependence of reflectivity on sun altitude angle, azimuth angle, and incidence look angle for two types of targets. It was found that for low sun altitudes, reflectivities changed radically with incidence angle and azimuth angle.

Test Procedure

The basic building block in this procedure for obtaining multi-spectral reflectivity data is a Minolta 1° Autospot Light Meter. The meter's angle of light acceptance is 1° resulting in sample areas of 50 to 100 square inches at distances of 35 to 50 feet. These distances are convenient for field measurements particularly for agricultural targets where fences prevent a closer approach. At these distances the incidence angle with the vertical will be between 80 and 85 degrees. The correlation between these large incidence angles and the smaller angles encountered with aerial photographs will be discussed later. The meter is calibrated in arbitrary units called luminance values. However, each meter is provided with an individual factory-made conversion chart which converts these luminance values to foot lamberts which are linear with respect to percent reflectivity.

The spectral components of reflectivity were obtained by placing filters in the meter's optical path. These were Wratten (47, 75, 58, 72B, 25, 89B, and 87) narrow-band absorption filters resulting in approximate system bandwidths of 50 nanometers, and peak transmission wavelengths separated by approximately 50 nanometers (Figure 2). It was considered that these filters provided a good general spectral reflectivity curve over the specified range (400–800 nanometers). A Corning 3961 filter which transmits in the visible and absorbs in the infrared was used in series with the narrow band gelatin filters in the visible portion of the spectrum as the gelatin filters do not absorb near infrared radiation.

The slight overlap in sensitivity between adjacent bands was considered desirable so that in the event an object exhibited an abnormally high reflectivity at some wavelength near the dividing point it could be detected. Such as anomaly would be seen as an increase in reflectivity in both adjacent bands. In any specific study it may be necessary to choose new filters to accentuate best some target of interest, and herein lies one usefulness of the test. First a general curve may be produced. If certain areas of the spectrum then exhibit good contrast ratios between target and background new filters in this region may be selected and a new test performed with them to determine the optimum filters. All of this may be done quickly and inexpensively before the multispectral mission is flown.

Calibration for each reading was accomplished by using an Eastman Kodak standard 18-percent reflectance gray card. Measurements made by Kodak Research Laboratories on this card indicated that the reflectivity of the gray card was 18 ± 0.5 percent between 380 and 900 nanometers. Each time a set of data samples were measured in the field the gray card was also measured in all spectral bands.

It should be noted here that because each set of readings is referenced to the gray card, there is no dependence on atmospheric conditions or illumination quality (provided the

Abstract: *In planning remote sensing missions with multiband photography in the visible and near-infrared regions, few investigators have ready access to the spectral information needed to choose the appropriate filter combinations. A technique has been developed by which one may pre-test to determine the optimum filter combinations and the feasibility of such a multiband mission. The test provides multispectral reflectivity curves not only for the targets or categories to be identified, but also for those backgrounds against which they are usually encountered. The procedure incorporates a method for determining spectral reflectance as a function of solar altitude, incidence look angle, and azimuth look angle. This angular dependence of reflectivity can be significant and might be used as an aid in detecting certain targets. It was found that for one target-background pair (asphalt and grass) the contrast ratio can range from 2:1 to 0.5:1 under different angle conditions.*

illumination source is continuous over the range of the test) thus the reflectivity values obtained with this test are independent of atmospheric paths. When using these data for planning a multispectral mission, it is necessary to take into account atmospheric attenuation between the remote sensor and the earth in the spectral bands of interest. Atmospheric attenuation and scattering are factors with which the remote sensor must constantly be concerned and their effects are well documented (Horvath, et al., 1969; Gates, 1966; Elterman, 1964). Each time a data sample is read in the field the time of day, direction in which the meter is pointed, and incidence look angle are recorded along with the luminance value. A computer program has been written (Egbert, 1970) which converts the Footlambert readings to percent reflectivity and calculates the angles defined in Figure 1 from the recorded field angles. The program also sorts the data by categories and calculates statistical parameters.

In order to test the accuracy of this procedure, readings were taken and spectral reflectivity curves were made of several different colors of art paper. Readings were also taken under several incident lighting conditions to illustrate that the calibration procedure eliminates a dependency on the quality of the incident illumination. A sample of the resulting curves are compared in Figure 3 with curves for the same papers made by Kollmorgen Color Measurement Service using a General Electric Recording Spectrophotometer No. 7015E30. As seen in the figure, the curves match extremely well which demonstrates the capability of this

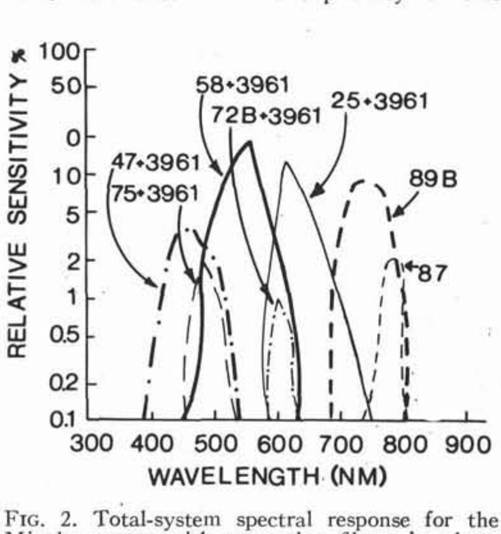

FIG. 2. Total-system spectral response for the Minolta meter with respective filters in place.

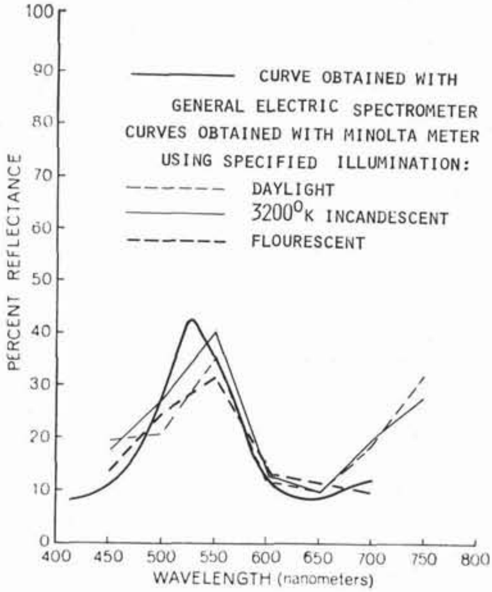

FIG. 3. Comparison of spectral reflectivity curves for green paper.

procedure in producing reliable spectral reflectivity curves. Some curves obtained with fluorescent lighting do, however, show a marked variation especially at the longer wavelengths. This is probably due to the line spectra nature of fluorescent illumination and indicates the necessity of using a continuous spectra illumination source for multispectral studies.

GEOGRAPHIC STUDY

In order to determine the utility of using spectral reflectivity measurements obtained in the field to aid interpretation, this procedure was implemented in conjunction with a geographic study mapping roads from color, color separations, and multispectral space photographs (Henderson, 1970). Photographs from the Apollo IX SO-65 experiment and the Apollo VI flights were used. The test site chosen for the study was the Dallas-Ft. Worth, Texas, area both because of the extent and quality of its space photography coverage and its relatively close proximity to the Kansas University Lawrence campus. Because of the coarse resolution of the space photographs, all textural and shape information was lost and only the difference in reflectivity between the road surface, shoulders, and right-of-way, and the background land use was useful for mapping.

The part played in the study by the spectral reflectivity curve test was to determine

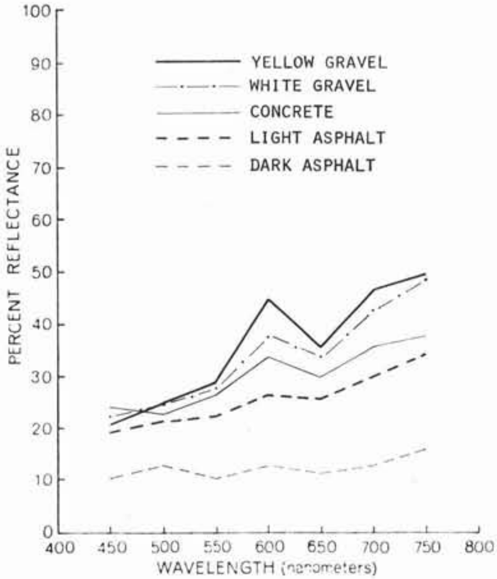

FIG. 4. Spectral reflectance curves for the five road surfaces in the Dallas-Fort Worth study.

if a study of the curves would indeed yield the information to predict the most efficient spectral bands for road detection and to establish the relative importance of the following factors in road detectability: road surface, actual road width, total right-of-way width, and adjacent land use.

For the reflectivity measurements the roads were divided into five categories according to road surface as follows: concrete, light asphalt, dark asphalt, yellow gravel, and white gravel.

Figure 4 shows the spectral reflectivity curves for these five road surfaces. Examination of these curves shows that the gravel road surfaces have a higher reflectance at all wavelengths (except 450 nanometers) than the paved road surfaces. Thus, the contrast ratios between roads and background land-use categories will be higher for gravel roads than for paved roads; on this basis gravel roads should be more easily detectable than paved roads. However, detectability of gravel roads was practically impossible whereas paved roads were detected fairly well (Henderson, 1970). As the road types go from divided highway (concrete or asphalt) to bladed earth (gravel) the percentage detected drops progressively, but the contrast ratios actually increase; thus it can be concluded that road surface has very little effect on detectability. The more important factor is actual road width. The road width goes from approximately 75 feet for divided highways to 16 feet for dirt roads. Thus, a high correlation occurs between road detectability and road width.

To determine the importance of total right-of-way width and adjacent land use on road detectability it is necessary to study the reflectance curves in Figure 5 for road ditches and the background land uses most often encountered in the study area. In the visible region it seems that very little difference exists between the reflectances of the different categories. Special notice should be taken of the reflectance curves for road ditches. These curves are indistinguishable from several vegetated background land-use category curves which indicates that total right-of-way width is relatively unimportant to road detectability unless the background land use is bare ground. In general, background land use is a more important factor in the detectability of roads than is total right-of-way width.

Now it is possible to list the four factors previously discussed in their order of importance to road detectability: road width, background land use, total right-of-way width, and road surface. Road width is by far the most important factor whereas land use and right-of-way width are inter-related and their influence on detectability is complex. Finally, road surface has little effect on detectability by itself; however, road surface

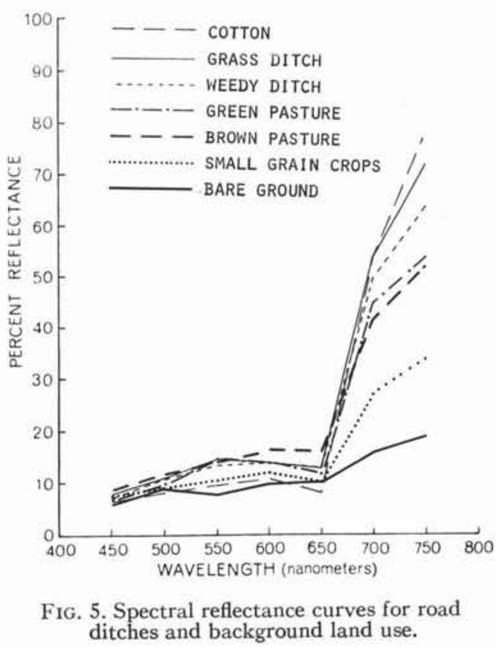

FIG. 5. Spectral reflectance curves for road ditches and background land use.

is related to road width so that without reflectance data it seems that road surface is important. A gravel surfaced super-highway would be as easily or more easily detected than a concrete or asphalt super-highway.

The space photography and color separations are available in the blue, green, red, and infrared bands only. From contrast ratios calculated from Figures 4 and 5 for roads and backgrounds in these regions, the order of utility can be *predicted* as follows: blue, red, green, and infrared. However it was found that the *actual* performance of the bands is ranked as follows: red, green, blue, and infrared (Henderson, 1970). The reason for the shift in importance of the blue band is almost certainly due to atmospheric effects. The atmospheric scattering and absorption is most severe in the blue region (Elterman, 1964). This obviously is an important consideration in space photography because the entire vertical atmospheric path must be penetrated. Except for the blue region the results of the image interpretation agree with the predictions based on the contrast ratios between roads and backgrounds.

In the red and green regions the percentage of roads detected was higher on the color separation plates than on the multiband photos. This is probably due to the fact that the color-film sensitivity in these regions overlaps (Sorem, 1967) and is more sensitive in the yellow region than the multiband, and the absolute maximum contrast ratios were found to occur in the yellow region.

The results of this test validate the usefulness of this method for predicting multiband filters for use in remote sensing missions designed to detect a given type of target. The results of image interpretation agree with the predictions for the optimum spectral bands. Of course, it is still necessary to keep in mind the atmospheric effects and make allowances for them when choosing the final filters. In addition to providing a basis for choosing the optimum spectral bands the reflectivity curves provide additional information about the importance of background, road surface, and road width on detectability.

Variations In Reflectivity With Changing Sun Angles

As mentioned earlier, it was found that for certain combinations of solar altitudes and azimuth angles severe discrepancies in reflectance values occurred with large incidence angles. It was considered that these variations in reflectance might be useful as an additional tool for target discrimination if the exact

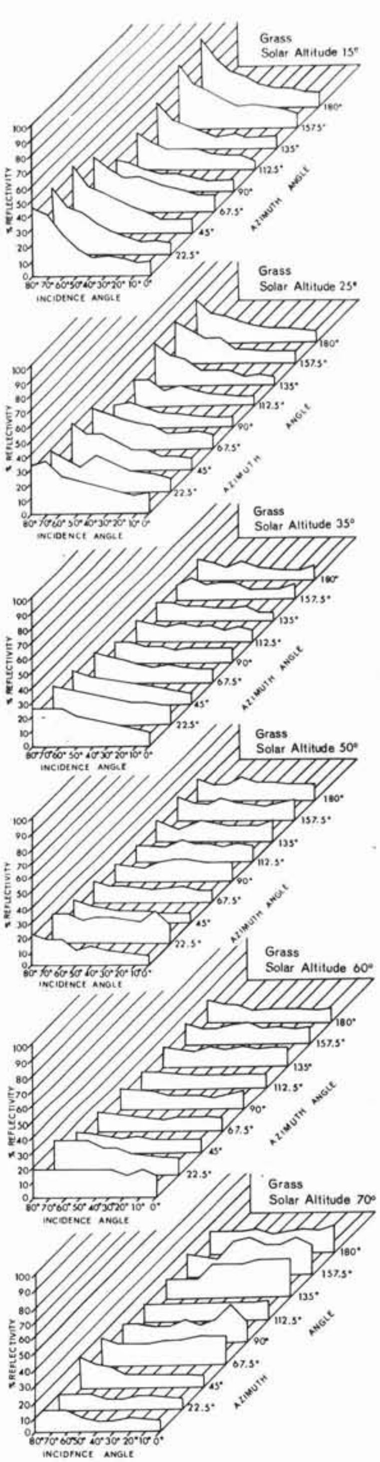

FIG. 6. Angular variation in panchromatic grass reflectance at specific solar altitudes.

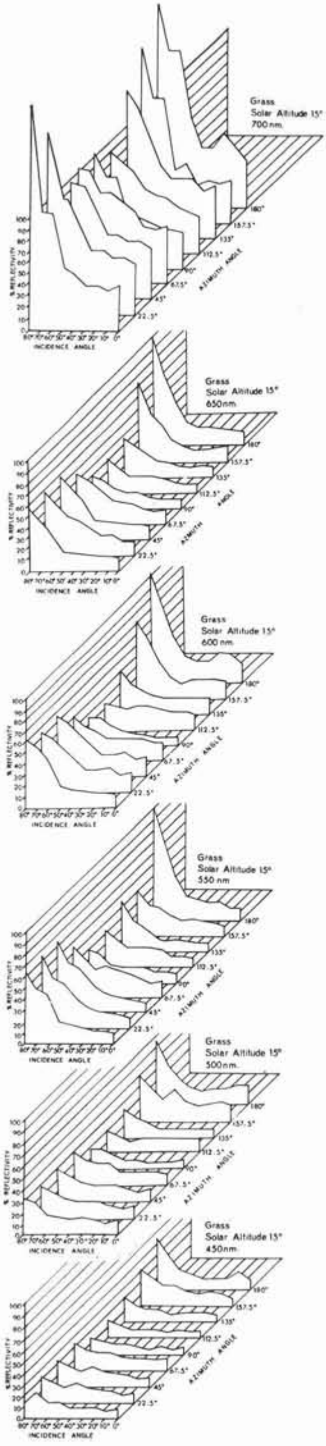

Fig. 7. Angular variation in grass reflectance in specific wavelength bands.

pattern of change could be determined. For example, at certain angles it is possible for a given target background combination to exhibit a higher contrast ratio than at other other angles. In order to determine the exact nature of these variations an experiment was designed to measure the spectral reflectance of specific targets under controlled angle conditions. The test was made on two examples, Kentucky 31 Fescue grass and asphalt paving.

The range over which each angle was varied in this experiment was as follows: solar altitude, 15° to 70°; incidence look angle, 10° to 80°; and azimuth angle, 0° to 180° (see Figure 1 for definition of angles). For the grass sample patch, nine azimuth angles were used. The reflectivity of the asphalt sample patch did not vary so rapidly with azimuth angle, hence the number of azimuth angles for asphalt was reduced to five by incrementing them by 45° instead of 22.5° over the interval 0° to 180°. In order to perform this experiment it was necessary to calculate the solar altitude angle and solar azimuth angle at given time intervals. A large protractor was constructed and centered over the data sample with its 0°–180° edge lined up with the solar azimuth angle. The protractor had a center section removed for the data sample and radial and circumferential lines for the different azimuth angles and incidence angles.

In order to obtain a sufficiently large viewing angle to provide an adequate sample size at the lower incidence angles, it was necessary to use a second light meter in addition to the Minolta 1° meter. A Sportron Pentaview meter was selected with an angle of acceptance of 10°. The Pentaview meter was used for 10°, 20°, 30°, 40°, and 50° incidence angles and then the Minolta meter for 60°, 70°, and 80°. By using both meters in this manner the size of the data sample area changed slightly from angle to angle but remained fairly constant over the entire range of incidence angles. The ideal instrument for the sun angle experiments would be a light meter with a zoom lens in addition to certain features found on the Minolta meter.

The two data samples chosen for this experiment (asphalt and grass) are exemplary of two wide classes of targets of interest in remote sensing. First the asphalt is a relatively smooth surface typical of most manmade targets such as roads buildings etc. The grass on the other hand is typical of nautral vegetation and certain types of small-grained agricultural targets. It should be noted however that these two samples are not presented as exhibiting identical reflectance characteristics as all other objects similar to them but merely as selected examples. In any particular application where the reflectance properties of a specific target are desired a test should be conducted for it. For example certain broad-leafed crops, such as sugar beets or corn, will surely exhibit characteristic reflectance patterns different from a bladed vegetation such as grass.

For analytical purposes the plots in Figure 6 were chosen to display the variations in reflectivity. These plots show the reflectivity of grass for all sun altitude angles from 15° through 70°. Notice that for a solar altitude of 15°, near 0° and 180° azimuth angle and for large incidence angles the reflectivity is almost 5 times greater than it is at 0° incidence angle and 90° azimuth angle. As the solar altitude increases beyond 35°, it is seen that the variation of reflectivity with azimuth angle and incidence angle decreases significantly and the grass behaves as a nearly perfect Lambertion reflector.

The reflectance variation from vegetation has been studied by Steiner and Haeffner (1965) and Hoffer et al. (1966). Hoffer presents a qualitative discussion of this phenomenon and offers an explanation using a simple geometrical model. Hoffer also states that the reflectivity variations will be different at different wavelengths. Figure 7 shows the reflectivity of grass at a solar altitude of 15° in each spectral band. As seen in these plots the reflectance variation with respect to angle is different in each spectral band although the general trend is similar. In all spectral bands the reflectivity increases at 0° and 180° azimuth angles and large incidence angles but those bands that have lower reflectance at 0° incidence angle exhibit a smaller relative increase at the extreme angles. It seems that each blade of grass acts as a random faceted reflector and, where the average reflectivity in a spectral band is high, the blades reflect and re-flect large specular components resulting in extremely high reflectance under the proper angular conditions.*

The asphalt paving sample exhibits a slightly different reflectance variation pattern

* Recent atmospheric radiation transfer studies indicate that variations in remote sensing reflectance measurements at low solar altitudes can have significant contributions from directional variations in atmospheric path radiance. See Turner, R. E., *et al*, "Importance of Atmospheric Scattering in Remote Sensing," *Proceedings of the Seventh International Symposium of Remote Sensing of Environment*, University of Michigan, Ann Arbor, Mich. May 1971, pp. 1651–1697.

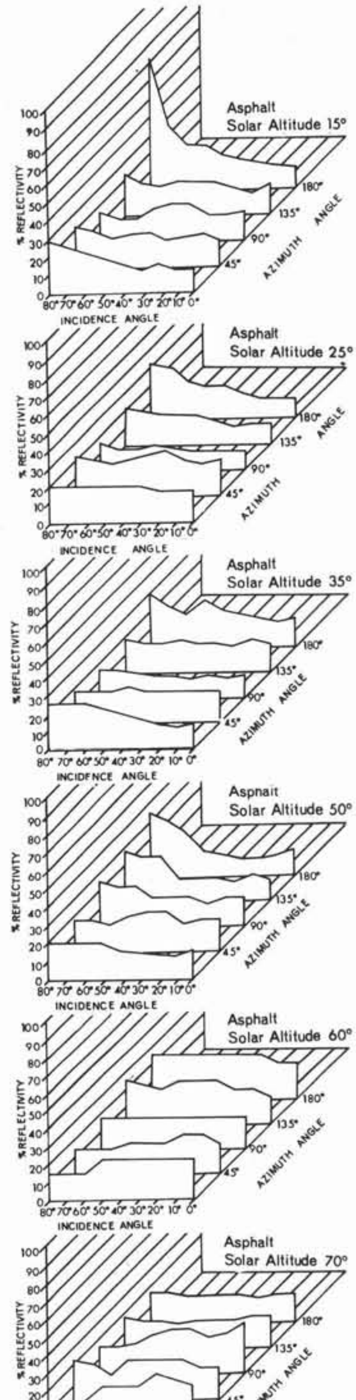

FIG. 8. Angular variation in panchromatic asphalt reflectance at specific solar altitudes.

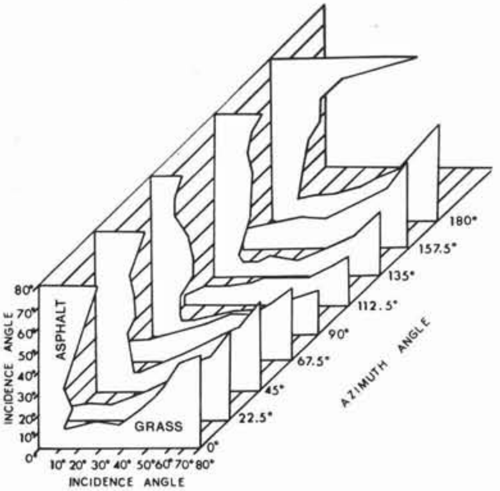

FIG. 9. Panchromatic angular variations in reflectance for grass and asphalt at a solar altitude of 15°. This graph is convenient for determining the angles that provide a maximum contrast ratio between a target and the background.

than the grass sample. Figure 8 shows the patterns for sun altitudes from 15° to 70°. The variations in reflectance as the azimuth and incidence angles vary are not as great for asphalt as for grass. The only extreme increase in reflectivity occurs at a sun altitude of 15°, azimuth angle of 180°, and incidence angle of 80°, and is the specular component of reflected light.

For zero-degree azimuth angle the reflectivity of asphalt does increase slightly as the incidence angle increases but not nearly as as much as grass reflectivity increases. This small increase is probably due to the small pieces of gravel imbedded in the asphalt. This gravel protrudes slightly above the asphalt surface itself and presents small specular reflectors at 0° azimuth angle.

As mentioned previously the wide reflectance variation with angle for some targets offers additional data for discrimination. For example the panchromatic contrast ratio between asphalt and grass is normally 2:1; however under certain conditions this ratio may reverse to as much as 0.5:1 i.e. grass can exhibit twice the reflectivity of asphalt instead of the normal one-half. In order for angular reflection variations to be used effectively complete information about a particular target's variations and its background's variations is necessary. A ground test similar to the one described here is a convenient method for obtaining these data and a convenient method for graphically displaying the reflectance variations for a target background pair is shown in Figure 9. In this way the angle conditions required for the maximum target to background contrast ratio may be readily found. Also possible adverse conditions which may decrease the contrast ratio can be detected and avoided in flying a multiband mission.

In the application where low altitude oblique photographs can be obtained for a specific study all three angles (altitude, azimuth, and incidence) can be controlled and used for optimum results. However, for high-altitude or space photography the experimenters control over these angles is limited. Figure 10 shows the geometry involved in vertical photography. The incidence angle can only be varied for vertical photography from about 0° to 23° and is controlled by the position of the target on the film frame. The azimuth angle is also controlled by the target's film position and may range from 0° to 180°. The solar altitude is under complete control within the limits of geographical location and solar declination for high-altitude photography. For space photography, however, the orbit will dictate what solar altitudes will be available for a given ground location.

In general, vertical photography is used for remote sensing missions and the standard minimum limit for the solar altitude is 30°. The results of this experiment confirm why this limit was set. Most of the reflectance measurements for sun altitudes greater than

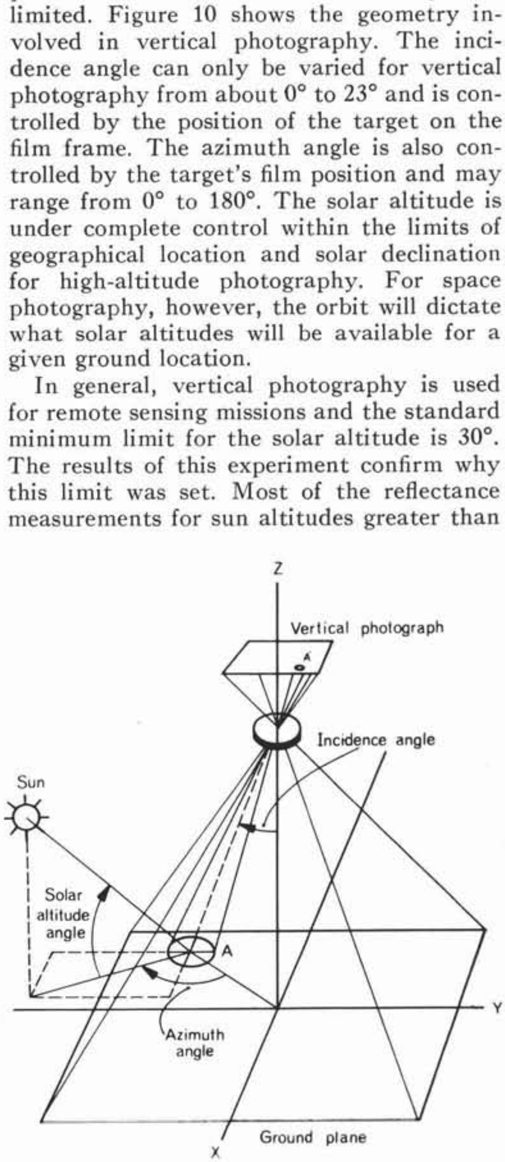

FIG. 10. Geometry of vertical photography showing the angles involved in the spectral reflectivity experiment.

30° are fairly consistent. However, if it is desired to use reflectance variations as a controlled parameter to aid in the detection of specific targets, lower solar altitudes may be essential.

Conclusions

This study has shown several advantages of using spectral reflectivity curves obtained in the field to aid in the interpretation of multiband images and the planning of remote sensing missions. In the Dallas-Fort Worth, Texas study the spectral reflectance curves together with a consideration of atmospheric effects accurately specified the proper spectral bands and provided valuable information for determining the importance of target and background parameters. Further it has been shown that angular reflectivity is different for various objects and can be used as a discriminate. Angular reflectivity variations have been presented for two samples and it has been shown that for these the contrast ratio varies from about 2:1 to 0.5:1. This indicates that controlling the solar, incidence, and azimuth angles can be a valuable procedure for remote sensing missions.

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