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VIEW ANGLE EFFECT IN LANDSAT IMAGERY*

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ABSTRACT

The objective of this paper is to investigate the view angle effect in LANDSAT II imagery. The LANDSAT multi-spectral scanner scans over a range of view angles of -5.78 to 5.78 degrees. The view angle effect, which is caused by differing view angles, could be studied by comparing data collected at different view angles over a fixed location at a fixed time. Since such LANDSAT data is not available, consecutive day acquisition data were used as a substitute: they were collected over the same geographical location, acquired 24 hours apart, with a view angle change of 7 to 8 degrees at a latitude of 35 to 45 degrees. The study will show that there is approximately a 5% reduction in the average sensor response on the second-day acquisitions as compared with the first-day acquisitions, and that the view angle effect differs field to field and crop to crop. On false infrared color pictures the view angle effect causes changes primarily in brightness and to a lesser degree in color (hue and saturation). An implication of this study is that caution must be taken when images with different view angles are combined for classification and a signature extension technique needs to take the view angle effect into account.

I. INTRODUCTION

A multi-spectral scanner (MSS) measures the ground radiance by varying its view angle across the flight path of its carrier. Sensor outputs are dependent upon, among other things, the instantaneous view angle corresponding to each output. The effect caused by differing view angles is called the view angle effect or the scan angle effect. The objective of this papper is to investigate the view angle effect in the LANDSAT II MSS**. The LANDSAT MSS scans a swath of 185km width on the ground from a height of 920km, so the view angle varies between -5.78 and 5.78 degrees.

Some of the previous work on view angle effect are reported in the following. Reflection properties of natural objects such as clay, sand, soil, and grass turf at varying view angles and zenith angles were studied by Coulson *et al.* [1,2] in the laboratory environment. Smedes *et al.*[3] investigated the view angle effect in the imagery acquired over the Yellowstone National Park area by an airborne 12-channel scanner whose view angle varies from approximately minus 40 degrees to plus 40 degrees. They introduced a normalized scan-angle function in order to reduce the view angle effect. Their results indicate that the view angle effect is larger near the nadir (zero degrees) than at the larger view angles.

This paper documents an investigation of the view angle effect in the LANDSAT MSS based on analysis of its imagery. This task could be performed by comparing data collected at different view angles over a fixed location at a fixed

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** Note that the results of this investigation are applicable to the LANDSAT I data because the two MSS's are identically designed.

time. However, such LANDSAT data is not available. Consecutive-day acquisition data were used as substitutes. Due to the LANDSAT orbit a certain portion of a LANDSAT full frame (185km by 185km on the ground) is also seen in a frame acquired on the next day [4,5]. Total view angle changes between consecutive-day acquisitions, which depend upon the latitudes of the ground area, are in the range of seven to eight degrees at latitudes of 35 to 45 degrees. Little attention to the view angle effect in the LANDSAT MSS has been paid in the past, possibly due to a common belief that such a small view angle variation would not affect the imagery. In this paper it will be shown that the effect is larger than expected. Moreover an attempt will be made to assess its rough order of magnitude.

II. MEASUREMENTS

One hundred and one consecutive-day acquisition pairs of LANDSAT subframes were used in this study. Each subframe consists of 117 scan lines by 196 pixels, covering an area of 9.0km by 10.8km on the ground. Among these frames there are 35 pairs of consecutive-day acquisition pairs which are 18 days (or one LANDSAT cyclic period with respect to the ground) apart (e.g. acquisitions on May 2, 3, 20, and 21). All the images are agricultural scenes from the United States and were acquired between April and August. The sun angles corresponding to the data are between 35 and 60 degrees. All images were screened visually and contain neither clouds nor visible haze.

The geometric registration of the imagery was assessed using a specially developed IMAGE REGISTRATION PROGRAM [6] for all acquisitions of the same location. The computed misregistration measurements ($\Delta x, \Delta y$) were rounded to the nearest integers and a simple shifting correction for misregistration was applied by these integer values along the scan line (Y direction) and/or the pixel direction (X direction). To further reduce the effect of misregistration, each frame (117 by 196) was smoothed by averaging and rounding the values in five scan line by five pixel areas, resulting in a 23 by 39 matrix.

Then scatter plots were made in the following manner. After the smoothing and rounding mentioned above are performed, two 23 by 39 integer matrices for the first-day and second-day acquisitions are obtained. A counter array, dimensioned 90 by 90 is defined and initialized to zero. The counters in the array are then incremented based on the values of geographically corresponding entries in the two matrices. If an entry pair for the first-day and the second-day acquisitions are 50 and 45, for instance, then the content of the counter at (50, 45) is incremented by one. This procedure is carried out for all 897 entry pairs from the two matrices. The final content of the counter array constitutes a scatter plot of the data. Resulting scatter plots are displayed as follows: the maximum counter value is found and the range from 0 to the maximum is divided into 10 equal ranges, which are denoted by ., 1, 2, ..., 9 in ascending order and are used in representing the scatter plot on a line printer. Blanks are used to represent null contents.

Since the LANDSAT MSS has four channels, four scatter plots were made for each consecutive-day acquisition pair. However, only the results for channel 3 will be shown because (1) all the four plots are fairly similar, (2) the effect of atmospheric conditions such as haze in channel 3 imagery is less than in channels 1 or 2, and (3) the effect of soil moisture in channel 3 imagery is less than in channel 4 imagery.

Figures 1(a), (b), and (c) show scatter plots made from three pairs of consecutive-day imagery on June 20 and 21, July 8 and 9, and July 26 and 27, respectively, from an area of 9.0km by 10.8km in Idaho. (It is extremely rare to have six straight acquisitions without clouds.) The diagonal line indicated by a series of '+' represents the y=x line. A scatter plot should be interpreted as follows: Consider x=50, for instance, in Figure 1(a). The range in y is from 44 to 49. So areas with count 50 in the first-day acquisition imagery had changed to counts of from 44 to 49 on the next day. It is reasoned that this scattering is primarily due to the view angle effect.

From these scatter plots it is observed that the majority of points are below the y=x line. That is, sensor outputs are generally smaller on the second day. This observation was confirmed by examining the 101 consecutive-day acquisitions mentioned earlier. Figure 2 shows a scatter plot where the x and y axes represent the entire subframe means on the first day and the second day, respectively. The least square solution y=.95x was obtained. In other words there is a reduction of 5% in average sensor outputs from the first day to the second day acquisition. The following is a possible explanation of this phenomenon.

On the first of the two days the sensor and the sun are both on the same side of the area that is common in consecutive-day imagery (see Figure 3(a)) so that the sunny side of standing objects is seen from the MSS. On the otherhand, on the second of the two days the sensor and the sun are on opposite sides of the common area (see Figure 3(b)) so that more of the shady side of standing objects is seen. If this explanation is correct, the view angle effect will be dependent upon such factors as shapes of objects, leaf orientation, spaces and materials between objects as well as sun angles.

Therefore the view angle effect for spaced standing objects such as trees and corn plants is reasoned to be different than that for objects with smooth surfaces such as lakes and soil. This is illustrated in an example shown in Figure 4.

The scatter plot is made from acquisitions on August 6 and 7 from an area in the state of North Dakota. There are 6 large lakes, which cover approximately 5% of the entire area. Generally, counts below 25 are from these lakes. It is seen that counts from the lakes increased on the second day while those from other objects decreased slightly. It is generally observed that counts from lakes tend to increase on the second day which is consistent with expectations because of mirror image reflectance of the sun off the water.

To study the behavior of each field, 20 fields were defined on the acquisitions used in Figures 1(a), (b), and (c) (see Figure 5). Temporal trajectories of ten fields are shown in Figures 6(a), (b), where x and y axes represent the field means of channels 2 and 3, respectively. (The trajectories for the remaining 10 fields were not plotted because they overlap with the above.) It is seen that temporal trajectories make zigzag motions when acquisitions with different view angles are mixed. This means that signatures are dependent upon view angles. Therefore caution is recommended when acquisitions with different view angles are mixed for any signature extension schemes.

On Figures 6(a) and 6(b) it is also observed that the trajectory on the second day moves toward the origin as expected due to lower values in both channels. This trend was also observed in channels 1 and 4 imagery. In other words, the change between consecutive day acquisitions is roughly proportioned in all channels. If false color infrared films are made for consecutive day acquisition pairs, they will look similar in color (hue and saturation) but differ slightly in brightness. After channel-to-channel ratio processing discussed by Smedes et al.[3] images would be generally free from the view angle effect.

III. DISCUSSIONS

There are other possible causes to explain differences observed between consecutive day acquisitions. They include:

(1) Effect due to precipitation - rain (possibly shower) may fall during a period of 24 hours.
(2) Effect due to moisture change - sunshine and wind may dehydrate soil and vegetation, altering reflectance.
(3) Effect of leaf orientation change due to wind.
(4) Effect due to scene change by irrigation, plowing and harvesting.
(5) Sensor noise and misregistration.

The degree of effects brought by these causes, except 5, differs from plant to plant or field to field. When a large number of cases are considered, all the above causes seem to act in a random fashion with zero bias. It seems to be a fair conclusion to say that the average of 5% reduction observed from the first-day to the second-day acquisition can be attributed solely to the view angle effect. For a particular consecutive acquisition pair we are unable to assess the relative magnitude of the view angle effect to the above effects although we believe the view angle effect is dominant.

However the above does not imply the existence of uniformly applicable view angle correction functions. As was seen in Figures 1(a), (b), and (c), the magnitude of the random unpredictable variability is generally larger than that of the predictable variability (i.e. 5% reduction). Also as are seen in Figures 4, 5(a), and 5(b), the differences between consecutive day acquisition pairs are dependent upon types of fields and vegetation. Therefore it can be said that there are no uniformly applicable view angle correction functions for the view angle range of plus 3 to 4 degrees to minus 3 to 4 degrees. This is not contradictory to the result of Smedes et al.[3], because the view angles of their MSS changed plus 40 degree to minus 40 degree. A view angle correction function can be used to grossly normalize imagery data for such a large view angle change.

REFERENCES

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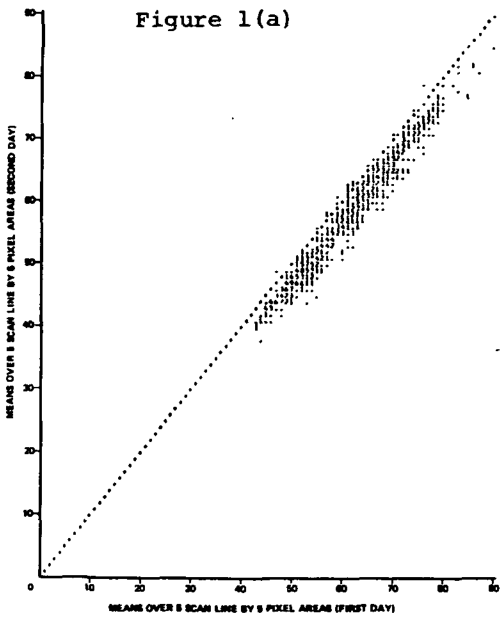

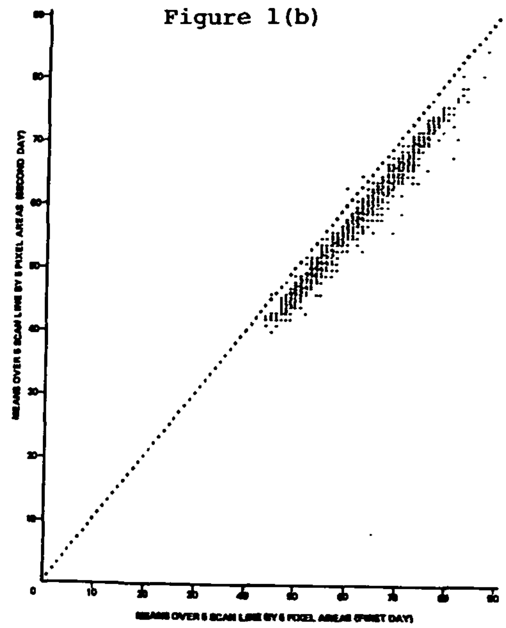

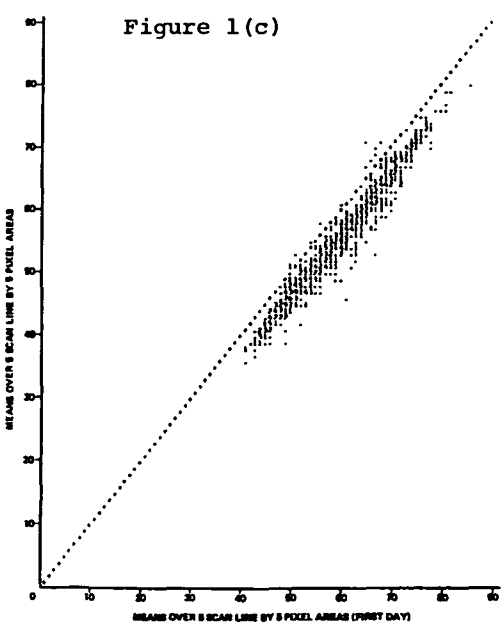

Figure 1(a) Scatter plot where x and y represent means over 5 scan line and 5 pixel areas on the channel 3 imagery acquired on June 20, and June 21, respectively.

Figure 1(b) Scatter plot where x and y represent means over 5 scan line and 5 pixel areas on the channel 3 imagery acquired on July 8 and July 9, respectively.

Figure 1(c) Scatter plot where x and y represent means over 5 scan line and 5 pixel areas on the channel 3 imagery acquired on July 26, and July 27, respectively.

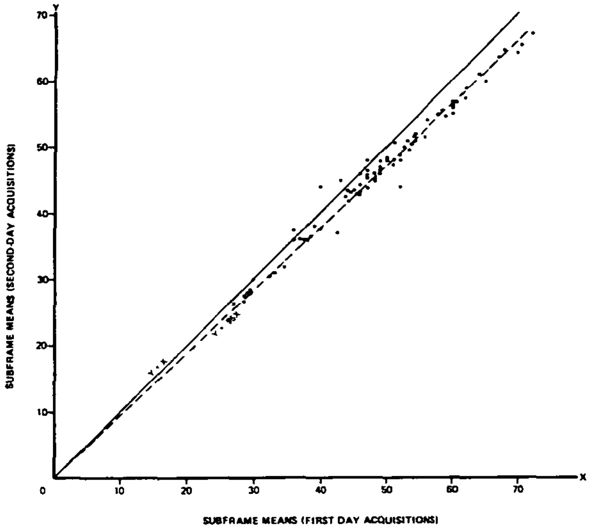

Figure 2 Scatter plot showing a 5% reduction in average sensor response on the second-day acquisitions as compared with the first day acquisitions.

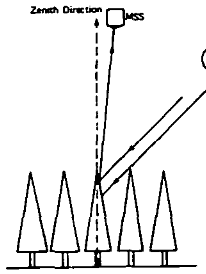

Figure 3(a)

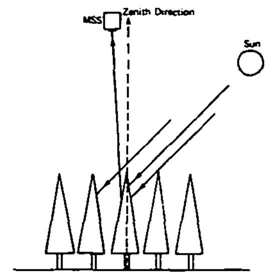

Figure 3(b)

Figure 3(a) Geometry of the sun, ground objects (trees), and the MSS for first-day acquisitions.

Figure 3(b) Geometry of the sun, ground objects (trees), and the MSS for second-day acquisitions.

Figure 4 Scatter plot made from a consecutive-day acquisition pair where 6 lakes constitute approximately 5% of the total subframe area. Note that counts below 25 are from these lakes.

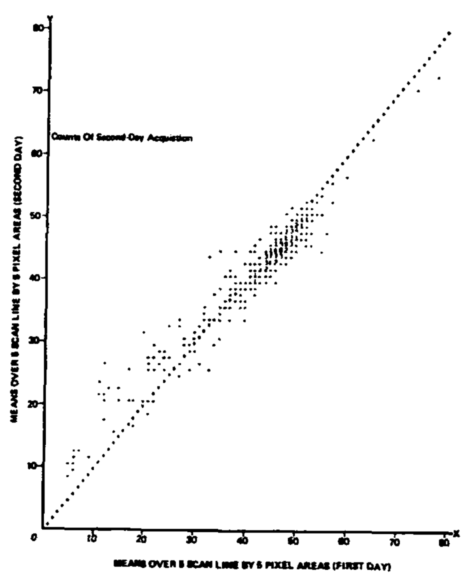

Figure 5 Channel 2 imagery of the subframe area used for Figures 1(a), (b), and (c) with 20 fields overlayed.

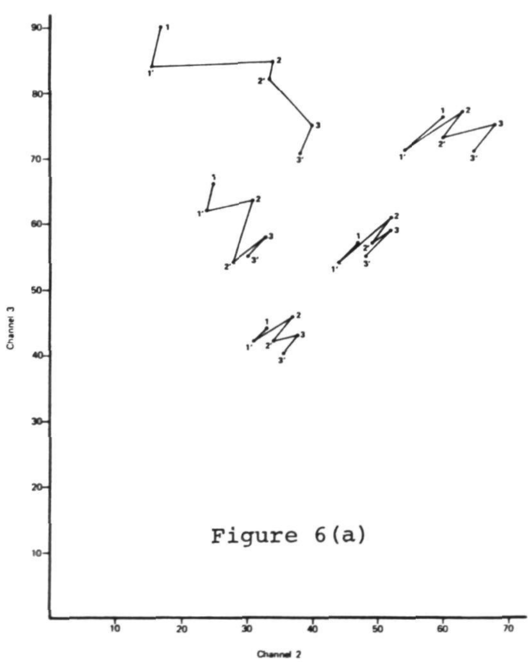

Figure 6(a)

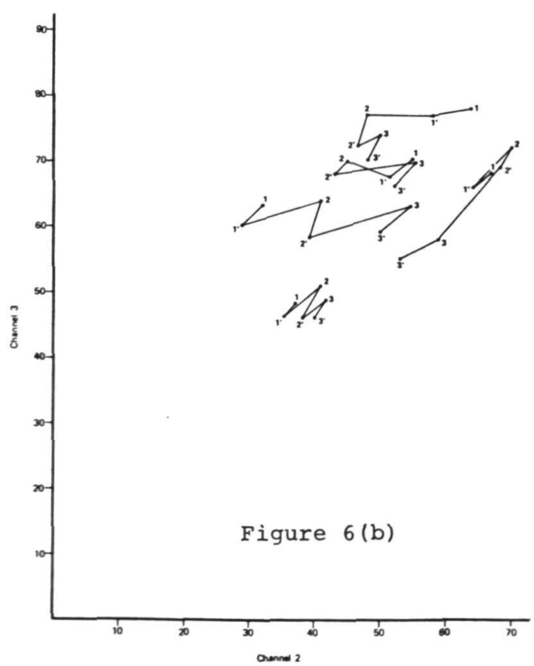

Figure 6(b)

Figures 6(a) and (b) Temporal trajectories of ten fields (1 = June 20, 1' = June 21, 2 = July 8, 2' = July 9, 3 = July 26, and 3' = July 27).