INTERACTIVE DISPLAY/GRAPHICS SYSTEMS

FOR REMOTE SENSOR DATA ANALYSIS

by

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INTRODUCTION

Using a color-television display system and interactive
graphics equipment on-line to an IBM 360/44 computer, investigators
at the Manned Spacecraft Center have developed a variety of inter-
active displays which aid in analyzing remote sensor data. This
paper describes how such interactive displays are used to:

1) Analyze data from a multispectral scanner.

2) Develop automatic pattern recognition systems based on
   multispectral scanner measurements.

3) Analyze data from non-imaging sensors such as the infrared
   radiometer and microwave scatterometer.

DESCRIPTION OF DISPLAY/GRAPHICS SYSTEM

The work described in this report was performed in the
computer laboratory of the Manned Spacecraft Center Information
System Division. This laboratory includes a Digital Television
Display System (DTDS) and a Grafacon tablet on-line to an IBM 360/44
digital computer.

HARDWARE

The DTDS consists of eight channels of recirculating memory each capable of storing a complete 729-line television frame. The system hardware includes a symbol library which makes it possible to display the various alphanumeric characters at any specified location within the frame as in Figures 9 - 13.

The intensity at each raster point within the frame is encoded in the recirculating memory using a single binary bit; i.e., each raster point is either on with full intensity or completely off. In order to obtain a gray scale the frame is divided into cells each of which can have a different number of raster points intensified. For example, in Figure 2 the intensity variation (in each color) was obtained by dividing the frame into 160 x 111 cells each having 5 x 5 raster points. The intensity of each cell is set by controlling the number (0 to 25) of intensified raster points. The various 5 x 5 dot matrices are stored as special symbols in the hardware symbol library.

Another important component of the DTDS hardware is the vector generator. This unit takes as its input the display coordinates of two points and automatically generates the display coordinates of all points on the straight line connecting them. This feature is used in forming the displays shown in Figures 17 - 19.

The display device used for all of the color photographs presented in this paper is the precision color monitor shown schematically in Figure 1. It consists of three cathode ray tubes having red, green and blue phosphors; each tube (i.e., color) is intensified by a separate channel of recirculating memory. The images on the three tubes are superimposed and projected onto a ground-glass viewing screen by a combination of mirrors, dichroic filters and a projection lens. Accurate registration of the three images is maintained by various electronic (e.g., deflection gain and centering) and mechanical (e.g., mirror alignment) adjustments.

Another output device connected to the DTDS is the Xerox hard-copy machine. It is used for copying black-and-white alphanumeric and graphic displays such as Figures 9, 10 and 19.

The user communicates graphical and alphanumeric information to the computer by way of a Grafacon tablet and a keypack, respectively. The Grafacon tablet is a device which 30 times per second transmits to the computer the instantaneous coordinates of

a pen held by the investigator. The tablet is 10 in. on a side and the coordinates are quantized to 0.01 in. As explained later, the operator uses the Grafacon pen to define certain areas and intervals of interest; for example, see Figures 3, 4, 17 and 18. The keypack, similar to a typewriter keyboard, contains all of the alphanumeric symbols. It is used to assign numbers to the areas and intervals of interest in Figures 3, 4, 17 and 18.

SOFTWARE

All of the programs used to generate the displays reported in this paper were written in FORTRAN IV. This was possible because the DTDS system is supported by an extensive software package consisting of many FORTRAN-callable assembler language subroutines (Reference 1).

DISPLAYS USED TO ANALYZE MULTISPECTRAL SCANNER DATA

INTRODUCTION

The multispectral scanner collects radiant energy from a small area (i.e., resolution cell) on the ground and separates it into spectral components in each of twelve wavelength bands between 0.40μ and 1.00μ . The instantaneous output signals are recorded and subsequently converted to numbers in the range 0-255 by an analog-to-digital conversion process.* The instantaneous field-of-view is scanned rapidly across the flight-line by a rotating mirror; the data is sampled at 222 points within each scan line. Successive scan lines are displaced along the flight line by the forward motion of the aircraft. The result is that multispectral scanner measurements are specified (i.e., referenced) on the basis of three independent variables: 1) scan line, 2) sample within a scan line, and 3) channel number.

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*The multispectral scanner data presented in this paper was processed by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University. In addition to the multispectral scanner data, LARS also provided the ground truth information necessary to conduct pattern recognition studies.

COLOR DISPLAY OF MULTISPECTRAL SCANNER DATA

Figure 2 is a photograph taken from the Digital Television Display System color monitor showing an approximately natural-color picture of the ground scene as reconstructed from the multispectral scanner data. This display consists of Lines 1 to 160 in the horizontal direction and Samples 1 to 111 in the vertical direction; this represents an area 2/3 x 1/2 mi. on Purdue Flight Line C-1 flown on June 26, 1966.

At each display cell the intensity of the blue, green, and red is set according to the multispectral scanner outputs at that particular Line and Sample in Channels 2, 6 and 10 (i.e., radiance measured at that particular ground cell in the spectral ranges 0.44-0.46μ , 0.52-0.55μ , and 0.66-0.72μ , respectively). For each of the three different colors the user can specify the intensity (one of 16 levels) associated with any multispectral scanner output (in the range 0-255). The user can also associate any one of the twelve multispectral scanner channels with each of the three colors; in this way a variety of "false-color" displays can be generated.

The necessary annotation data is included as an integral part of the display. For example, the following information is recorded in the top line of Figure 2:

1) The blue, green, and red intensities depend on Channels 2, 6, and 10, respectively.

2) The data is from Purdue Flight Line C-1 flown on 26 June 1966.

3) The display consists of Lines 1-160 and Samples 1-111 in steps one.*

INTERACTIVE METHOD FOR ENTERING GROUND-TRUTH INFORMATION

One of the most important functions which an investigator

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*The program also has a provision for displaying every other Line and/or every other Sample.

must perform in analyzing remote sensor data is to put ground-truth information into the computer. The Digital Television Display System is well-suited to this requirement in that it 1) displays a complete frame rather than a single scan line at a time, 2) is available immediately rather than requiring film processing, and 3) is responsive to on-line keyboard and graphical input devices.

In processing multispectral scanner data it is necessary to put into the computer certain training and/or test fields (Reference 2). These are areas where the material classification (e.g., crop-type) is known from a ground-truth survey. In the interactive system developed at the Manned Spacecraft Center the investigator uses a Grafacon pen to outline fields he recognizes in the natural or false-color display shown in Figure 2.

Movement of the Grafacon pen causes a <u>corresponding</u> line to be displayed on the monitor. Using this display, the investigator moves the pen so as to outline the field of interest.* Once the boundary has been closed the computer responds by erasing the enclosed field from the display. The investigator then uses the keypack to type in the field number designation for this area.

The investigator is assisted in the interactive dialog with the system by computer-generated instructions displayed in the upper-left corner of the frame (e.g., see Figure 3). The table on the next page gives the sequence of instructions and the investigator's response. A short 16 mm color movie (NASA/MSC # S-70-370 available from the authors) shows the procedure used to set into the computer the boundaries of several different fields.

Figure 4 shows the result of outlining all fields within the frame. Here all areas (except roads) have been erased from the display leaving only the boundaries and associated field numbers. This information is also printed out in the form of a Xerox hard-copy for permanent documentation.

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*It should be emplasized that the fields can have any shape and orientation; for example, see Figure 3.

Computer-Generated Instruction	Investigator's Response
OUTLINE A FIELD	Use the Grafacon pen to outline the area of interest.
DRAW BOUNDARY AGAIN	Outline the area again, this time making sure to close the boundary.
POSITION FIELD NUMBER	Use the Grafacon pen to point to the place in the erased area where the field number should be displayed.
TYPE FIELD NUMBER	Use the keypack to type in the number associated with the outlined area.

GROUND-TRUTH MAP

The boundary information shown in Figure 4 is recorded on magnetic tape and used in subsequent processing to derive a ground-truth map in computer-readable form. This is a magnetic tape giving the material-type at every point (i.e., Line-Sample combination) within the outlined areas.

To obtain the ground-truth map the investigator only needs to specify (in the form of data cards) the material-type to be associated with each field number.* Using an algorithm described in Reference 3, the computer automatically "fills in" the outlined fields with the designated material-types and records the result on magnetic tape. In this way a ground-truth tape was prepared for the entire flight line and is available from the authors.

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*In the case of the data presented here (Purdue Flight Line C-1, June 26, 1966) the necessary information resulted from a ground-truth survey conducted by the Laboratory for Applications of Remote Sensing.

Figure 5 is a color coded ground-truth map formed by displaying Lines 1 to 160 and Samples 1 to 111 of the ground-truth tape. In this figure the colors red, green, yellow, and blue represent areas of soybean, wheat, oats, and bare soil, respectively. The white areas are fields where no crop-type designation was available.

COMPUTER DERIVED LAND-USE MAP

Using algorithms described in the next section the computer processes the multispectral scanner data to determine automatically what material is present within each resolution element. This determination is based on data from several (e.g., four) channels at any given point.

The computer-derived results are displayed in the form of a color coded land-use map such as Figure 6. In this display the color assigned to a given point (i.e., Line-Sample combination) depends on the crop-type derived by the computer. As in Figure 5 the colors red, green, yellow and blue represent areas of soybean, wheat, oats, and bare soil, respectively.

ERROR MAP

By comparing Figures 5 and 6 it can be seen that the computer derived results generally agree with the actual ground-truth. To facilitate this comparison an error map display was developed. This is a presentation showing the correct crop-type (as its own distinctive color) at every point where the computer derived classification is incorrect; areas correctly classified (and white areas where no crop-type designation was available) are left blank. Figure 7 is an error map which shows the differences between Figures 5 and 6.

DISPLAYS USED FOR PATTERN RECOGNITION RESEARCH

INTRODUCTION

The term "pattern recognition" is often applied to the various computer-based methods by which material-type classifications are derived automatically from multispectral scanner measurements. The

pattern recognition process can be explained by reference to
Figure 8. Here a point in the three-dimensional vector space repre-
sents the tip of a <u>measurement vector</u> having as its components the
measured outputs from three spectral bands at a single resolution
cell on the ground. The pattern recognition process is based on the
fact that measurement vectors for different materials tend to cluster
in different regions of measurement space. Pattern recognition
systems operate in two stages:

1) The multidimensional measurement space is partitioned into
   non-overlapping regions associated with each type of
   material. The regions may be described analytically
   (Reference 2) or prestored in computer memory (Reference 4).

2) The measurement vector for each resolution cell is analyzed
   to determine which region it occupies in measurement space.

The displays shown in Figures 9 - 16 were developed to aid in the
design of such pattern recognition systems.

MULTIDIMENSIONAL HISTOGRAM

In order to observe the clustering of measurements from a
given material it is helpful to plot in three-dimensional space the
measurement vectors of all resolution cells inside the training
fields for that material; this is shown in Figure 8. It is possible
to present this same information in two dimensions by plotting only
those points which fall within a specified <u>slice</u> (i.e., range of
values) in the third dimension. For example, in Figure 8 a training
sample having the value x in Channel X, the value y in Channel Y, and
a value in the range z_1 to z_2 in Channel Z is plotted at the point
(x, y). A multidimensional histogram for a given material is
formed by counting the <u>number</u> of training samples at the point
(x, y) and in the range z_1 to z_2.

Figure 9 is a multidimensional histogram for soybean. This
type of display is a quantitative version of the "Color-Space" plot
described by Holter (Reference 5). At any point in the Channel 1 -
Channel 9 plane is given the number of soybean training samples
which are in the range 151 to 158 for Channel 11 and the range 179
to 186 for Channel 12. The material-type and the Channel 11 -
Channel 12 slice are specified at the top of the display. The

range* of values in Channel 1 and in Channel 9 are displayed on the horizontal and vertical axes, respectively.

Figure 10 is a histogram for corn plotted over the same range in Channels 1 and 9 and for the same slice in Channels 11 and 12. From Figures 9 and 10 it can be seen** that multispectral scanner measurements from corn lie above and to the right of measurements from soybean. The computer-based pattern recognition system to be described next uses this as a basis for discriminating between soybean and corn.

CLASSIFICATION SPACE

As explained previously, pattern recognition involves partitioning the measurement space into non-overlapping regions associated with each material-type. A common analytic method for deriving the classification space assumes a Gaussian probability density function and employs a maximum-likelihood decision rule.

Equation (1) gives the probability that Material i gave rise to the given measurement vector X.

$$P_i(X) = \frac{1}{(2\pi)^{N/2}|K_i|^{1/2}} \cdot \exp[-1/2(X - M_i)^T K_i^{-1}(X - M_i)] \quad \text{Eq. (1)}$$

where:

P_i = Probability density function for the ith material
X = Measurement vector for a particular ground cell
N = Number of channels used
M_i = Mean vector for the ith material
K_i = Covariance matrix for the ith material

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*The display provides only 16 points along the horizontal and verti-
  cal axes; however, each point can represent any integer number of
  multispectral scanner units. For example, in Figures 9 and 10 each
  point represents a cell 3 x 3 multispectral scanner units in
  the Channel 1 - Channel 9 plane.

**The arrows in Figures 9 and 10 point to the same position in the
  Channel 1 - Channel 9 plane. These arrows were inserted for the
  convenience of the reader and are not part of the computer-
  generated display.

The mean vector M_i and the covariance matrix K_i which appear as parameters in Equation (1) are evaluated from the training samples of Material i. These are measurements from resolution cells inside training fields similar to the ones outlined in Figure 4.

The maximum-likelihood decision rule classifies a given sample as Material i if the probability of Material i computed from Equation (1) is higher than the probability of any other material. However, it is sometimes preferable to assign a sample to the category "Unknown" rather than misclassify it. This is accomplished by the parameters L and D in the decision rule given by Equation (2).

CLASSIFY THE GIVEN GROUND CELL AS MATERIAL i IF:

$$P_i (X) \geqslant L \cdot P_j(X) \text{ and}$$

$$1/2 (X - M_i)^T K_i^{-1} (X - M_i) \leqslant D$$

Eq. (2)

where:

L = Likelihood ratio

D = Threshold distance

Here a sample is classified as Material i only if the following two conditions are met:

(1) The probability of Material i must be at least L times greater than the probability of the second most likely material.

(2) The normalized distance between the measurement vector and the mean vector for Material i must be less than D.

Displays were developed to study the effect of L and D on the classification space.

Figures 11 - 16 are classification space displays. For specific values in Channels 11 and 12 they show at each point in the Channel 1 - Channel 9 plane the material-type derived from Equations (1) and (2). To facilitate comparison with the multidimensional histograms the range of values in Channel 1 and in Channel 9 are the same as for Figures 9 and 10. Also the specific values for Channels 11 and 12 (i.e., 154 and 182, respectively) are in the middle of the Channel 11 - Channel 12 slices.

Figure 11 shows the classification space for the case L = 1

and D = 1000; this corresponds to the maximum-likelihood decision rule. In this display the letters S, C, O, R, W, and Y represent soybean, corn, oats, red clover, wheat and rye, respectively. Figure 12 shows the case L = 5 and D = 1000. Here no classification is made unless the probability of the most likely material is at least five times the probability of the second most likely material. The result is that regions on the boundaries between different materials are classified as "Unknown" (i.e., no classification is made). Figure 13 shows the case L = 1 and D = 15. Here no classification is made if the measurement vector is further than the specified distance from the mean vector. In four-dimensional measurement space a threshold setting of D=15 excludes the correct classification less than 1% of the time.

In Figure 14 the region of measurement space associated with soybean is represented by the yellow area* for the case L = 1 and D = 10. The effect of increasing the threshold distance to D = 20 is to expand the soybean region to include the red area below and to the left. The reason the expansion is not symmetrical will be discussed in connection with Figure 16.

Figure 15 is a composite display formed by superimposing the multidimensional histogram for soybean (see Figure 9) on the soybean classification region. It can be seen that almost all the samples are correctly classified because they fall within the soybean region. Shown in red are the number of soybean samples which would be incorrectly classified as some other crop-type or classified as "Unknown".

Figure 16 is a composite display formed by superimposing the multidimensional histogram for corn (see Figure 10) on the soybean classification region. Shown in yellow are the number of corn samples which would be incorrectly classified as soybean. From this figure it can be seen that expansion of the soybean classification region upward and to the right would result in many corn samples being misclassified as soybean. This is the reason for the asymmetrical expansion of the soybean region in Figure 14 when the threshold distance was increased from 10 to 20.

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*This area is equivalent to the area cut out from the classification mask in the "light-pencil" technique for pattern recognition developed at the University of Michigan (Reference 5).

DISPLAYS USED TO ANALYZE NON-IMAGING SENSOR DATA

INTRODUCTION

Unlike the multispectral scanner, many sensors produce output signals which cannot be displayed in the form of imagery such as Figure 2. This limitation results from the fact that they a) have very poor resolution and/or b) provide only a line scan over the ground scene. Non-imaging sensors currently used in the Earth Resources program include the infrared radiometer, infrared spectrometer, microwave radiometer and microwave scatterometer.

In order to analyze data from these non-imaging sensors it is helpful to display their output signals in spatial registration with ancillary imagery of the ground scene. References 3 and 6 describe a method for producing computer-generated transparencies which are superimposed over aerial photographs to show the exact sensor boresight path and the resulting output signals. Using these overlays an analyst can a) determine the sensor response for various materials which can be recognized from the photograph and/or b) identify the material which gave rise to any given sensor response.

This overlay approach has been extended to permit on-line interactive analysis using the Digital Television Display System. The black and white aerial photograph (e.g., a 9 x 9 in. RC8 camera frame) is scanned by a closed-circuit television camera and the resulting video signal is presented on the green tube of the precision color monitor. The computer-generated graphics showing the sensor boresight path and the output signals are displayed on the red tube. The two displays are superimposed* and projected onto the ground-glass viewing screen as shown in Figure 1. Using the Grafacon pen and the keypack on-line to the computer the analyst can define flight path intervals over which the computer processes the sensor data. This approach will be explained by reference to infrared radiometer and microwave scatterometer data.

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*The magnification and alignment of the closed-circuit television camera are carefully maintained so that the resulting image on the monitor is in exact spatial registration with the computer-generated graphics.

INFRARED RADIOMETER

The green part of Figure 17 is the closed-circuit television presentation of RC8 Frame 4419 taken during Mission 102. It shows an island (actually a spoil sand bank) adjacent to the intracoastal waterway south of Corpus Christi, Texas; the surrounding dark areas are cloud shadows. The red part of Figure 17 is computer-generated graphics showing the sensor boresight path* and resulting output signal from the infrared radiometer. From this display it is apparent that the path of the sensor passed directly over the island and that the island was significantly warmer than the surrounding water.

The analyst interacts with the display by defining certain intervals along the sensor boresight path. He does this by using the Grafacon pen to point to the beginning and ending points of each interval. The computer responds by displaying a short mark across the sensor path at the selected position; six such points define three different intervals in Figure 17. After the analyst signals that he has set in all intervals of interest the system responds by computing the average sensor signal over each interval. The three average temperatures are displayed across from their corresponding intervals in Figure 17.

MICROWAVE SCATTEROMETER

Figure 18 shows the boresight paths and output signals for four different look-angles of the microwave scatterometer. The look-angles (displayed in the upper-left corner) are 2, 5, 10, and 20 degrees forward from nadir. Sigma Zero, the reflectance coefficient for each look-angle, is plotted in spatial registration with the ground scene. It is apparent from this display that the reflectance coefficient increases as the beam passes over the island.

As before, the analyst interacts with the display by using the Grafacon pen to define intervals along the sensor path. In the case of the microwave scatterometer, however, the computer responds by

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*References 3 and 6 describe in detail how the sensor boresight path (relative to aerial photographs) is computed using aircraft guidance and navigation data recorded in flight.

displaying the average value of reflectance coefficient for all four look-angles in each interval. For example, in Interval #1 the average reflectance coefficients are -6, -16, -33, and -37 decibels for look-angles of 2, 5, 10, and 20 degrees, respectively.

The system also produces a Xerox hard-copy showing a graph of the reflectance coefficient versus look-angle for each interval. Figure 19 gives the microwave scatterometer signatures for the three intervals defined in Figure 18. Such displays can be used to determine whether the signatures are different enough to permit discrimination between materials of interest.

CONCLUSIONS

An interactive display/graphics system has been developed for remote sensor data analysis. This system has the following advantages over other systems being used currently:

1) It displays digital data in color a full frame at a time.
2) The display is available immediately because no photographic processing is involved.
3) It permits the analyst to interact with the display and the data processing.

The display system has been used in the following applications:

1) Natural and false color displays of multispectral scanner data.
2) Ground-truth and land-use maps.
3) Multidimensional histograms and classification-space plots for pattern recognition research.
4) Displays showing non-imaging sensor data in spatial registration with ancillary imagery.
5) Microwave scatterometer signatures.

The interactive graphics capability has been used for the following purposes:

1) To define training and test fields by setting into the computer boundaries and ground-truth information.
2) To define intervals along the boresight paths of non-imaging sensors.

The development of such systems has considerable programmatic importance in that they make it possible to analyze large quantities of remote sensor data in a short time.

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4. W. G. Eppler, C. A. Helmke, and R. H. Evans, "Table Look-Up Approach to Pattern Recognition," Proc. 7th Symp. on Remote Sensing of Environment (University of Michigan, Ann Arbor), May 1971.

5. Marvin R. Holter, "Research Needs: The Influence of Discrimination, Data Processing, and System Design," Chapter 9 in Remote Sensing with Special Reference to Agriculture and Forestry, National Academy of Sciences, Washington, D. C., 1970, pp. 372-374.

6. W. G. Eppler, "Accuracy of Determining Sensor Boresight Position During Aircraft Flight-Test," Proc. 6th Symp. on Remote Sensing of Environment (University of Michigan, Ann Arbor), pp. 205-225, October 1969.
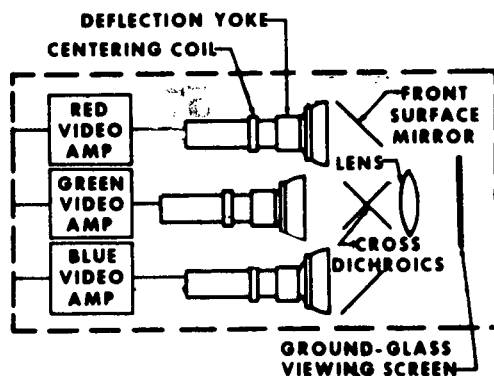
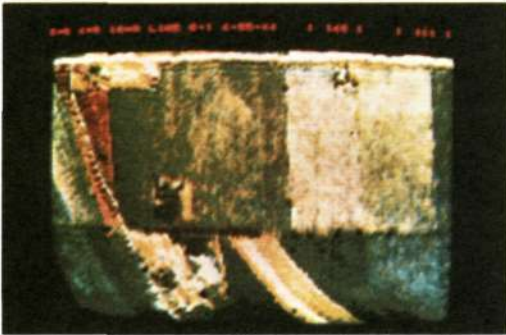Figure 1.-Schematic diagram of precision color monitor.

Figure 2.- Natural-color display
of multispectral scanner data.

Figure 3.- Interactive method for
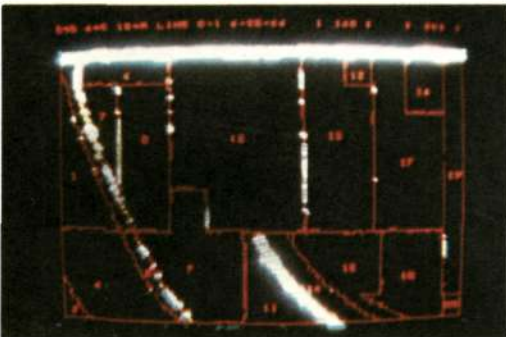entering ground-truth areas.

Figure 4.- Completed boundaries
for ground-truth areas.

Figure 5.- Display showing color
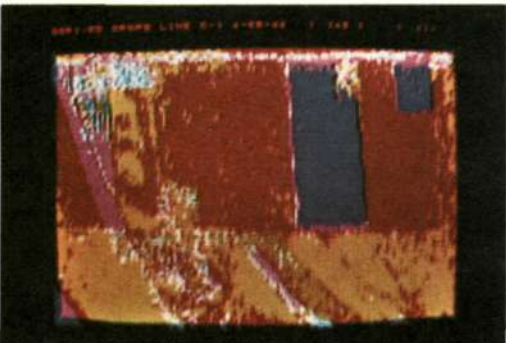coded ground-truth map.

Figure 6.- Display showing com-
puter derived land-use map.

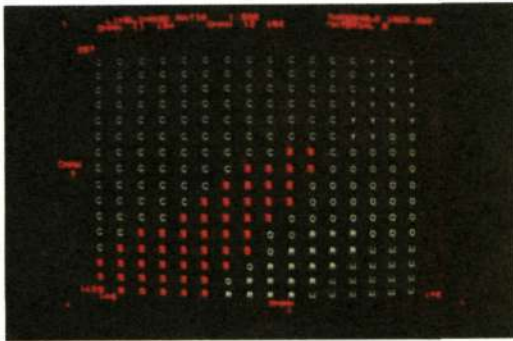Figure 7.- Errors in the computer
derived land-use map.

Figure 8.- Multispectral scanner data
represented as points in three-
dimensional measurement space.

11 151 158   12 179 186   MATERIAL S
209

CHANNEL
9

```
                        2 11  3  1  ←
                      4 12 57 17
                   13 38 61 77  9
                   13 78 58 72 36
              1  87 216 58 19  4  1
              7  97 175 28  8  2
              8  68 49  4
           1  8 19 12  1
              2  4  4
```

162
 145
                        1
                              CHANNEL   192
                                 1

Figure 9.- Multidimensional histogram
for soybean.

11 151 158   12 179 186   MATERIAL C
289

CHANNEL
9

```
                              1
                        1  2  7 13  2
                       15 26 24 28  3
              1     7 74 55 17  1
              2 27 67 26  4
              7 28 28  9  1  ←
              2  2  5
           1
                        1
              1
```

162
 145
                              CHANNEL   192
                                 1

Figure 10.- Multidimensional histogram
for corn.

Figure 11.- Classification space
derived using L=1.0 and D=1000.
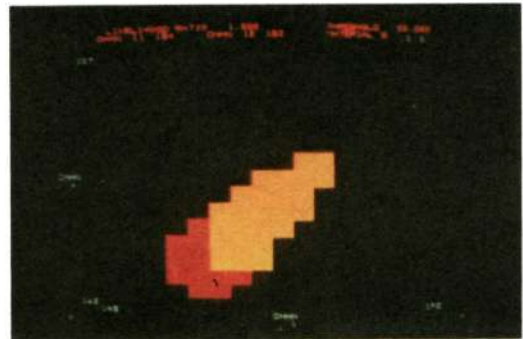
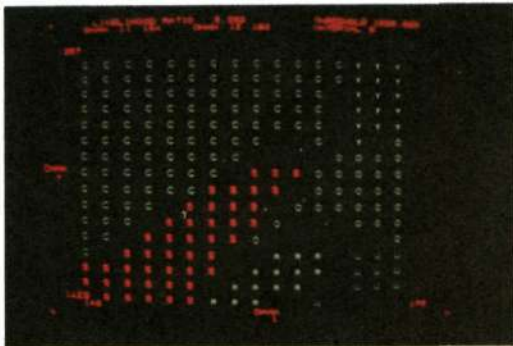Figure 14.- Areas classified as
soybean for D=10 and D=20.

Figure 12.- Classification space
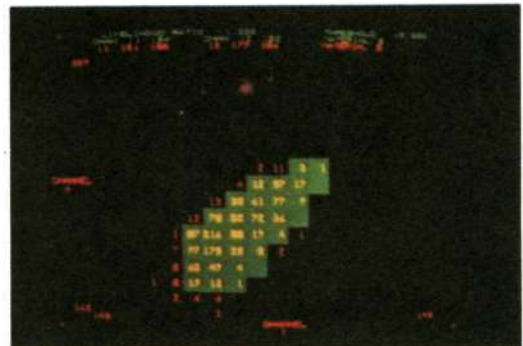derived using L=5.0 and D=1000.

Figure 15.- Soybean histogram on
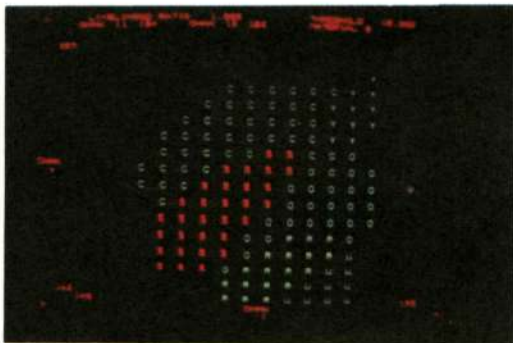area classified as soybean.

Figure 13.- Classification space
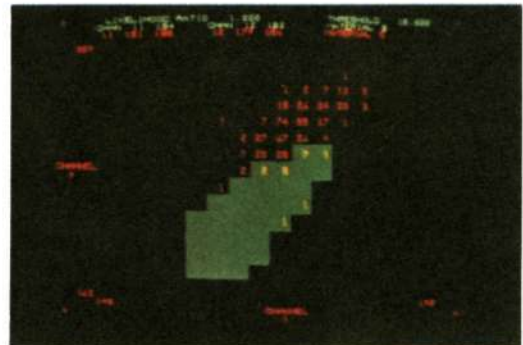derived using L=1.0 and D=15.

Figure 16.- Corn histogram on area
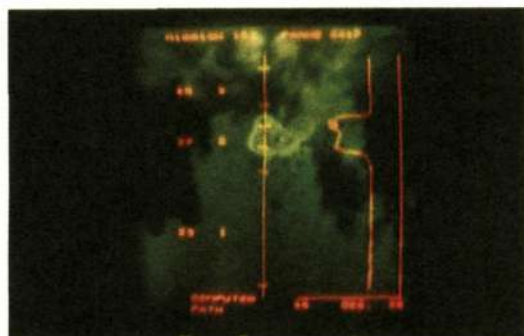classified as soybean.

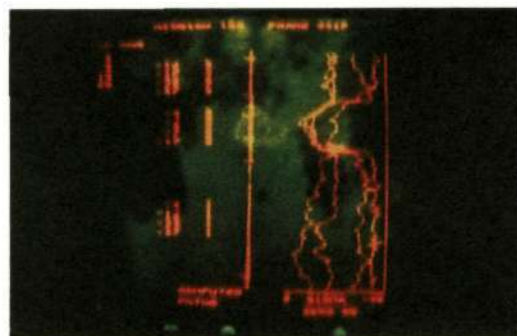Figure 17.- Boresight path and sensor return for infrared radiometer.

Figure 18.- Boresight path and sensor return for microwave scatterometer.

MISSION 102 SITE 175 FLIGHT FCF 3 LINE 2 FRAME 4419
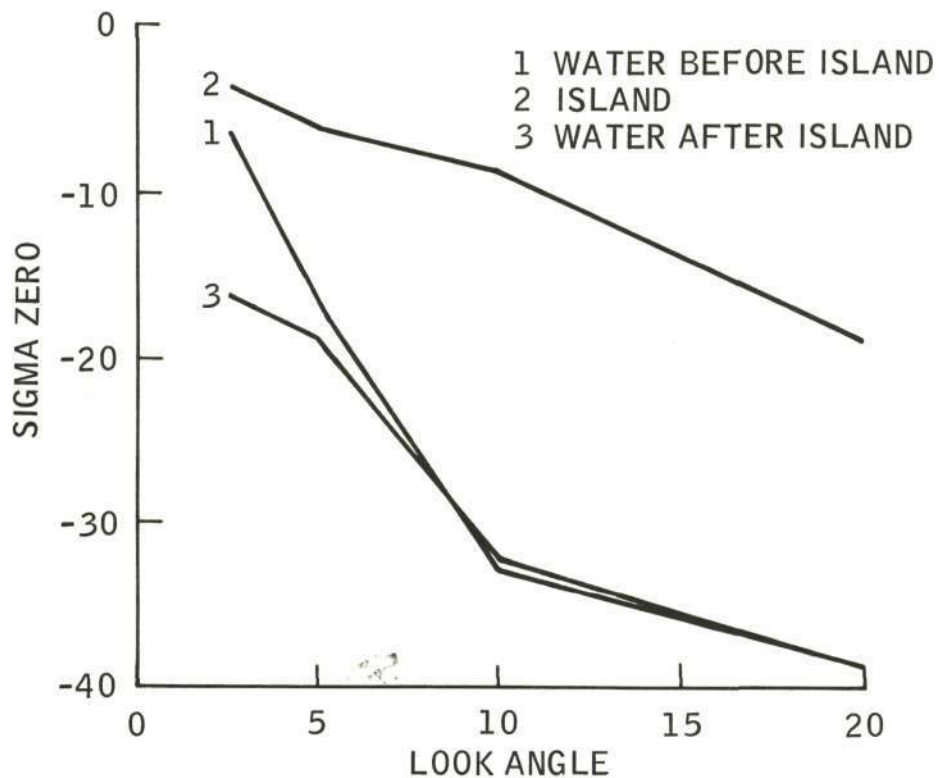

1 WATER BEFORE ISLAND
2 ISLAND
3 WATER AFTER ISLAND

Figure 19.- Microwave scatterometer signatures for three different flight-path intervals.