FIG. 1. SCORE processing complex.

JAMES D. TURINETTI
RANDOLPH J. HOFFMANN
Rome Air Development Center
Griffiss AFB, N.Y. 13441

Pattern Analysis Equipment and Techniques

A highly flexible interactive multispectral image processing system has been developed to enhance/extract characteristic features for application to reconnaissance problems.

(Abstract on next page)

INTRODUCTION

OVER THE past few years, developments in remote-sensing technology have provided the research community with high-quality imagery and large quantities of data from selected portions of the Electromagnetic Spectrum (EMS). The impact of this high volume of data with respect to processing requirements has been described by Nagy (1972) and Marshall (1971), and indicates the necessity to develop automated processing techniques to exploit this available material. This capability to sample the EMS in various bands (density features), coupled with laboratory and field studies of the spectral properties of material (patterns) has precipitated the application of pattern-recognition technology to automate the processing and/or analysis of remotely sensed data (Landgrebe, *et al.*, 1969; Erickson, 1972).

In addition to the inherent spectral characteristics of materials, the use of image-forming devices enables the investigation of other image features such as texture (Haralick, 1972) and contextual spatial information. The application of pattern-recognition techniques utilizing these measurable features has been investigated for a large variety of applications from land-use studies (Turinetti, 1972) to urban planning (Dueker, 1971). Our interest in automated processing of remotely sensed data is to aid the photointerpreter by cueing him to areas of probable interest and to present additional information, extractable through the correlation of multisource data, to aid in the identification function.

Due to the variety of remote sensors currently available and planned, it became apparent that some system to enable full exploitation of remotely sensed data must be available in the future. A research tool was required to provide the capability to apply processing techniques to extract and evaluate both spectral and spatial features to be used as the basis for classification logic design. The general pattern recognition problem can be divided into three interrelated areas: preprocessing, feature extraction, and classification design (Viglione, 1970).

At Rome Air Development Center (RADC), this last phase has been implemented in a general processing system known as On-Line Pattern Analysis and Recognition System (OLPARS) (Sammon, 1970). OLPARS is an interactive software system which provides the capability of analyzing and displaying the inherent structure of a particular data set and of designing non-parametric classification logic based on the selected features. However, OLPARS does not provide the capability of performing the preprocessing or feature extraction functions. These functions are extremely problem dependent and are usually accomplished on an ad hoc basis by investigators intimately familiar with the specific problem.

ABSTRACT: *The purpose of this paper is to introduce the remote sensing community to an interactive analysis system which was designed and implemented at the Rome Air Development Center, and to report on some preliminary investigations utilizing the capabilities of the system to provide meaningful features for automated classification of multispectral inputs.*

Approximately three years ago a program was initiated at RADC to develop and implement a digital image processing system which would provide the capability of performing the preprocessing and feature extraction functions that were not available on OLPARS. The design objective for the system was to provide a flexible processing system that would accommodate a variety of image inputs and permit development of processing methodology for preprocessing and feature extraction from remotely sensed data. The image inputs range from a single photographic input, whose features fall under the category of textual and contextual spatial information, to multisource image inputs which add spectral features to the possible features to be measured.

The single input problem was addressed under a program known as Image Feature Extraction System (IFES) and the multisource or multispectral problem under a program known as Spectral Combinations for Reconnaissance Exploitation (SCORE) These two programs have been combined by implementation of common hardware and also common software except for specific application programs. In the remainder of the discussion, the processing system will be referred to as the SCORE Complex. This capability to perform feature extraction, coupled with existing OLPARS provides the research tools of investigating automated processing techniques to aid in the image-interpretation function.

HARDWARE/SOFTWARE DESCRIPTION

The design objectives were satisfied by an interactive software system implemented on a PDP-11/20 computer interfaced to the Spatial Data System-800 Image Analyzer (Figure 1). The processing sequence is controlled by an analyst through an interactive software system which provides the capability of viewing the result of a processing algorithm immediately by means of the color image display. The system can accept photographic data (TV vidicon), digital data, and analogue line-scan data (7 channel A/D conversion station). The image data are stored in image files of 1024 × 1024 picture elements (pixels) on the RP02 disc. The application programs are stored on a fixed-head disc and the central processor of the PDP-11/20 has 28K of core. The software is controlled with a Tektronix 4010 display, and an SDS 800 color system provides the interface for viewing of a 384 × 496 portion of the image files on a TV raster display.

The processing sequence is controlled by interactive communication of the analyst and the software system. A list of processing options known as a frame is displayed to the analyst on the 4010 display. The analyst then selects the next stage of processing from the options available. The frames have been designed to provide a logical set of options from input through feature measurement and output in an OLPARS compatible format. The selection of an option either calls another frame of options or requests file names and other required input parameters from the analyst.

The processing algorithms are divided into functional modules: (1) inputs, (2) file manipulations, (3) statistics, (4) preprocessing, (5) feature measurement, and (6) output. The input function is as it implies—the necessary software to create an image file and input it from a specified device (camera, A/D station, digital tape). Under the file manipulations are the normal rename, select and directory functions, but also included are algorithms to select a specific sub area of the image for further processing, and *x-y* registration for multiple-image data. Statistics enable the computation of statistical parameters on the image files as well as the generation of spectral curves based on selected training areas within an image file. These spectral curves provide a visual inspection of the various classes under consideration as to the best spectral regions to be used for the basis of classification.

The spatial processing techniques include edge detection and enhancement, location of closed curves, smoothing, generation of high- and low-pass filters, noise elimination and other algorithms to reduce the variability of the image data prior to feature measurement. The inherent spatial characteristics are of extreme interest due to the size of most targets of military interest. The feature-measurements phase provides the capability of extracting values for the N specified features of a data point or area. The detected features are then measured and the numeric value together with the training-class identification is output to a digital tape for input to OLPARS.

At this point, OLPARS accepts the data by class and provides the capability of analyzing the data points for each class and for all classes in N-dimensional feature space. The purpose of this structure analysis is to determine if the data is uni- or multi-modal. If multimodal, the class is divided into two subclasses and processed as separate classes until the end, and then recombined. The type of structure analysis available is the generation of one-dimensional histograms, two-dimensional scatter diagrams and three-dimensional scatter diagrams. A valuable mapping algorithm is the non-linear map (Sammon, 1969) which permits N dimensions to be mapped and displayed in two dimensions while maintaining the interpoint distances of the data. Once the structure of the data has been analyzed, the next step is to invoke the Distribution-Free Logic Design Options. This module permits the computation of the optimum linear discriminant for separating and classifying the classes under study.

The linear discriminants available under this option to partition the feature space are Euclidean means, and Fischer's linear pairwise discriminant. The full power of this system is that after mathematical computation of the discriminants, the analyst can evaluate the results and, if they are not adequate, he can enter the loop and alter or even generate a piece-wise discriminant function, thus tailoring the classification design to the data under consideration without assuming any specific distribution. This classification logic is then output as a set of N-dimensional vectors associated with a threshold for each pair of classes in the design set. The unknown vectors are then evaluated in this pairwise fashion and the class obtaining the maximum number of votes is selected as the output of the classifier.

Preliminary Analysis

Due to the wide variety of problems that will be addressed with this system it is in a constant state of modification. However, even during development, some initial experiments are and will continue to be conducted. These initial studies are based on the use of spectral signatures as the features for classification. Remotely sensed images are extremely complex scenes in that many types and sizes of objects normally occur in an image scene. The usual approach to image classification is to determine the signature of each class and classify the entire image. This technique was investigated employing the OLPARS system to design the classification logic. This will be referred to as Case I. The Case II approach was somewhat different in that the scene was analyzed in an indirect manner to obtain the areas of interest. A model was built for all those categories that we knew and considered to be uninteresting. These points were identified and then removed, leaving only the areas which were unknown and required additional investigation.

The imagery used for the evaluation of these two schemes came from a nine-lens camera with Wratten filters, Kodak 2405 black-and-white double-X panchromatic film, and Kodak 2424 black-and-white infrared film. Each lens was filtered for a selected portion of the spectrum from 400 nm to 900 nm, and the bandpass areas, at 30 percent transmittance, varied from 20 nm to 46 nm in the six lenses covering the spectrum from 400 nm to 700 nm, and the 700 nm to 900 nm region of the spectrum was filtered in an overlapping manner.

The targets selected for this analysis were all in RADC's Northeast Test Area, and were selected because they each contained three or four of the following basic categories of materials: water, vegetation, bare soil, and man-made materials such as asphalt, concrete, metal, etc.

Figure 2* is a photo of a typical target used for this investigation. Some *a priori* knowledge of the area is required in order to construct the model. Here we knew the location of the vegetation, asphalt, bare soil and metal building, and we wanted to classify the remainder of the areas.

Using the interactive feature of the SCORE system, small areas on the imagery were identified and used as training sets for development of the class models. Each of these areas can be thought of as N nine-dimensional density vectors, with N being the number of points in the area.

For Case I all of these density vectors were submitted to OLPARS for logic design, and the resultant logic was implemented on the SCORE complex. Figure 3 is a gray-level coded map of the classification made with this logic. The logic was then applied to the imagery covering the opposite end of the airfield, and Figure 4 is a gray-level coded map of these classifications. Figure 5 shows the result when all of the gray levels except the one representing metal are filtered out via the SCORE equipment.

For Case II, all of the model information except that for the metal was utilized. It was assumed that everything on the airfield was known, except the location of the metal objects.

For this analysis a set of nine intervals was calculated, based on the mean and standard deviation of the densities for each category on each image. The nine intervals for one category became the model for that category. Every point on each set of images was then evaluated against this model. If the nine-dimension vector for the point matched with the model, it was identified as that category and coded white. If the vector was not compatible with the model, it was not classified and it was coded black.

The final step evaluated the set of classification overlays (black-and-white images), and identified all those points which were not identified on at least one overlay as any category. This was the overlay we were most interested in because it showed the location of points which needed further investigation. This overlay was analyzed to detect the edges on it and then superimposed back onto the original image to pinpoint the unknowns. Figures 6, 7 and 8 illustrate: a typical overlay for the bare soil on the scene, the unknown points on the scene, and the final image with the unknown areas located on the original image.

An interesting development has arisen

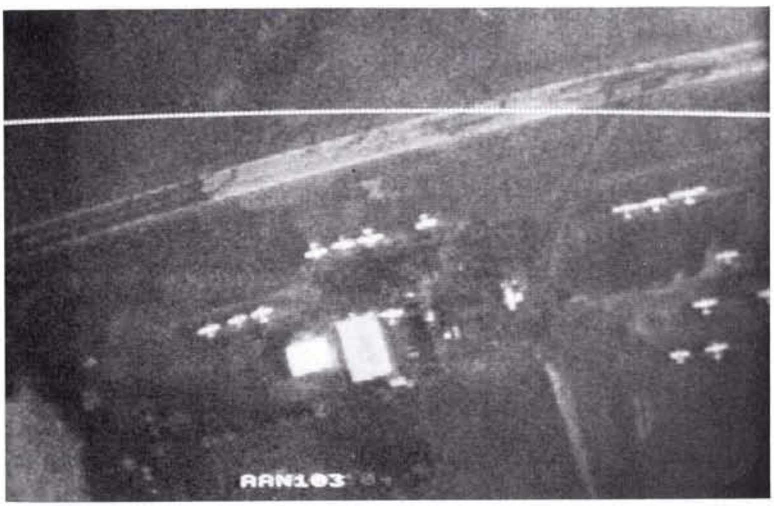

FIG. 2. Canastota Airfield (basic image).

* Figures 2 through 10 are photographs taken from the television display of the imagery.

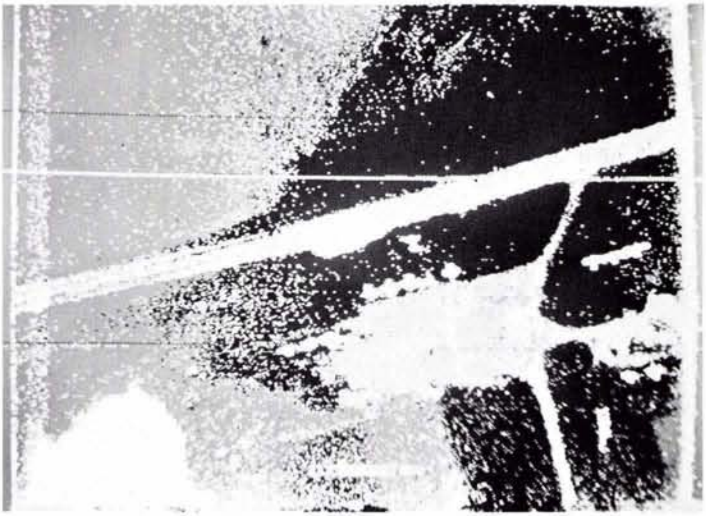

FIG. 3. Case I. Gray-level coded classification map.

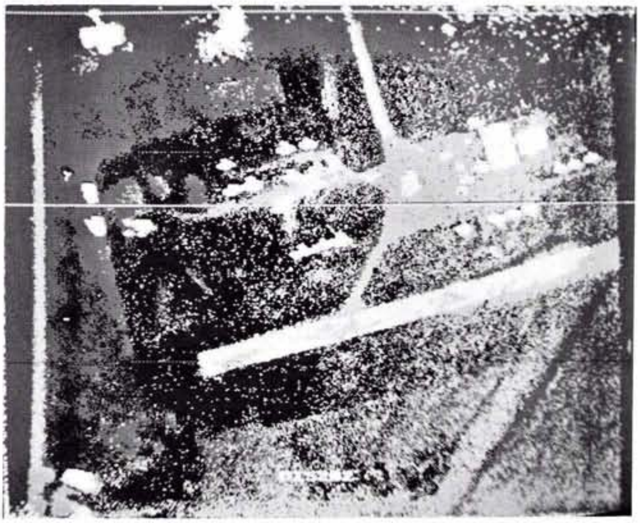

FIG. 4. Case I. Geographically displaced gray-level coded classification map.

from this analysis. By working with the overlays from all of the material categories of interest, it was possible to separate accurately a single material of interest with few ambiguities. As an example, we trained on one airplane, and then tried to find the rest of the airplanes on the imagery. Working with the overlays we queried the computer to display all those points which weren't vegetation, asphalt, bare soil nor water, but were airplanes. Figure 9 is the basic result of this work.

The analysis model from Case II was also employed on the imagery at the opposite end of the airfield as was done for Case I, but this time the results were totally unacceptable. The reason for this failure appears to be due to the change in the image characteristics caused by the shift in position of the target on the image format, and the dependence of the model on the parametric characteristics of the densities of the imagery.

Case II was also evaluated on a variety of image formats; nine-lens imagery, four channels of the ERTS MSS imagery, and imagery from an eleven-channel multispectral scanner, all with results similar and consistent with those illustrated in Figures 6, 7 and 8.

It is considered that these two analyses illustrate a number of points:

* The SCORE complex is a flexible and versatile system which can be extremely useful to the researcher in locating and identifying land-

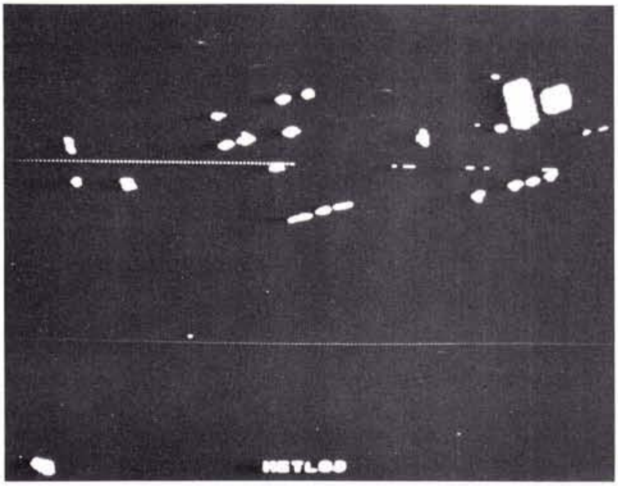

FIG. 5. Case I. Metal objects only.

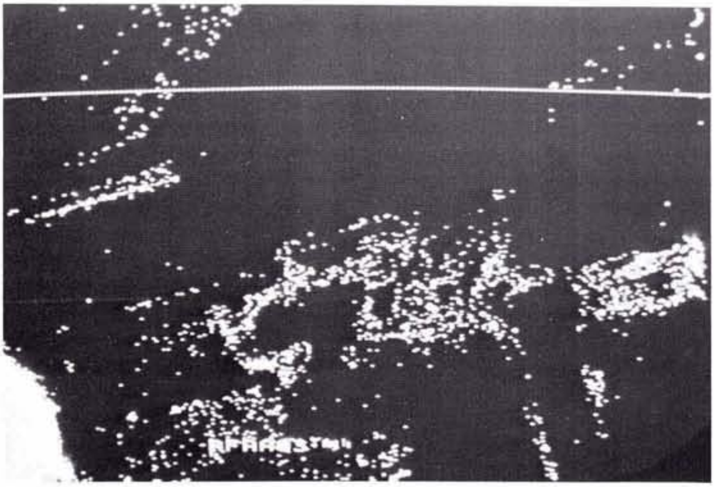

FIG. 6. Case II. Bare-soil overlay.

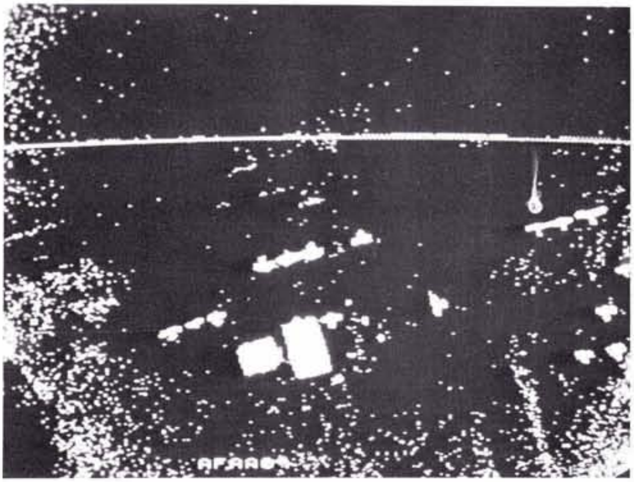

FIG. 7. Case II. Unknown-objects overlay.

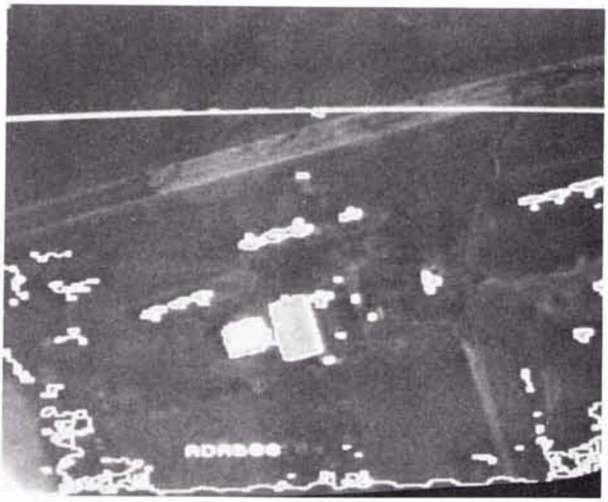

FIG. 8. Case II. Unknown-objects locations superimposed on basic image.

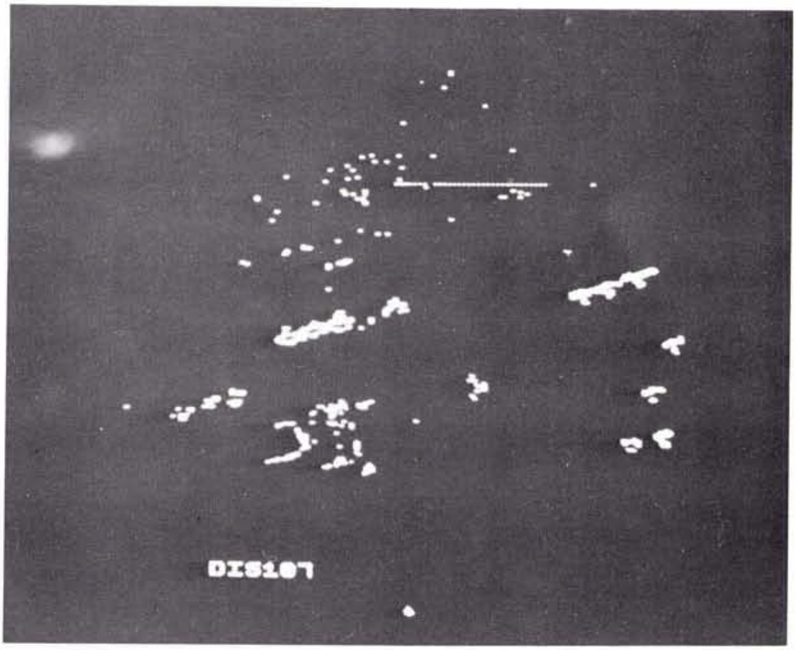

FIG. 9. Airplanes by process of elimination.

use categories and/or anomalies automatically using a variety of multispectral imagery.

* There are approaches and algorithms which can be employed with various forms of multispectral imagery to classify broad categories of materials automatically.
* More work is needed to investigate the normalization of data to enable the researcher to displace his investigation in a geographic or time-wise manner and maintain continuity within his data sets.
* Although Class II results were not easily extended beyond the training frame, it should be noted that the training areas areas were much smaller than the entire image and that the time required to conduct this simple classification scheme from data input to final result is less than 50 minutes for five classes. Therefore, depending on the specific requirement and amount of data to be analyzed, this simple logic approach may prove to be worthwhile in simplicity and time.

SUMMARY

A highly flexible interactive multispectral image processing system has been developed at Rome Air Development Center to provide analysis techniques to enhance/extract characteristic features of materials that can be utilized in designing automated classification logic. The application of pattern recognition philosophy to multispectral imagery has been directed toward reducing the search time currently needed by a photo interpreter and present additional information extracted from multispectral data in a format he can use to aid identification. The hardware/software capabilities of the system are described from the viewpoint of the interactive development of processing schemes to extract features to be used in classification. Two decision designs were utilized: (1) non-parametric design using Fischer's Pairwise Linear Discriminant, and (II) parametric design based on means and standard features of training classes. Case II produced reasonable results on a single frame but could not be extended to additional frames without redesign of limits. The non-parametric design enabled extension to other frames, but with some degradation. This indicates techniques to normalize or remove variability of the input data are essential to final classifier design.

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