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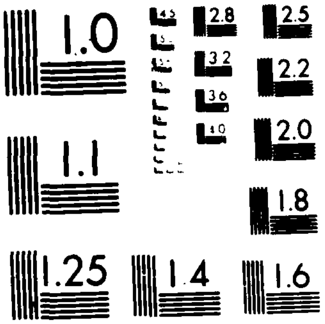

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1. REPORT NUMBER
USAETL R-092

N NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Automated Radar Image Analysis Research in Support of Military Needs

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Dr. Frederick W. Rohde, Dr. Pi-Fuay Chen, Mr. Richard A. Hevenor

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, VA 22060-5546

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, VA 22060-5546

12. REPORT DATE
Oct 86

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release.
Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DTIC
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APR 2 4 1987
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CD
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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Synthetic Aperture Radar
Image Analysis
Automated Terrain Feature Extraction
Automated Target Recognition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The U.S. Army Engineer Topographic Laboratories are engaged in research for exploiting imagery from synthetic aperture radar (SAR) to support military requirements. This paper presents a brief discourse of the methods and techniques that are applied in the research including image processing, descriptor and descriptor set development, and decision-making using artificial intelligence (AI) techniques. The status and accomplishments of the work are reviewed. The relevance of emerging capabilities in support of military needs is discussed in detail.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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ABSTRACT

The U.S. Army Engineer Topographic Laboratories are engaged in research for exploiting imagery from synthetic aperture radar (SAR) to support military requirements. This paper presents a brief discourse of the methods and techniques that are applied in the research including image processing, descriptor and descriptor set development, and decision-making using artificial intelligence (AI) techniques. The status and accomplishments of the work are reviewed. The relevance of emerging capabilities in support of military needs is discussed in detail.

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INTRODUCTION

Synthetic aperture radars (SAR) are high resolution radars that can be used for reconnaissance, surveillance, and terrain analysis. The high resolution in range and azimuth is achieved by pulse compression and phase history processing, respectively. SAR images have much in common with optical images such as aerial photographs. Both are characterized by tones, patterns, shapes, and shadows. There are, however, significant differences between SAR and optical images due to the differences in the wavelengths and in the illumination and reflection of the targets. Cloud cover presents an obstacle to optical imagery but not to SAR imagery because radar waves can penetrate cloud cover. Optical imagery provides more detailed information than SAR imagery because of its higher resolution. The resolution of optical imagery decreases with distance whereas the resolution of SAR imagery is independent of distance. For large distances, for example from satellites to the surface of the earth, the resolution of SAR imagery approaches the resolution of optical imagery. These properties make SAR a very useful tool for military purposes. SAR systems can collect large quantities of imagery. For the timely and economic analysis and interpretation of SAR imagery there is a need for the development of automated and interactive capabilities that will reduce the dependency on and requirements for highly trained image analysts.

PURPOSE AND GOALS

The purpose of this R&D effort is to provide new and advanced capabilities for radar image analysis and exploitation in response to military requirements. Table 1 lists some applications of SAR imagery to support military needs.

Table 1

Military Applications of SAR Imagery

Reconnaissance and Surveillance
Target Detection and Identification
Classification of Surface Materials
Terrain Analysis
Cross Country Mobility
Intelligence Preparation of the Battlefield

Radar images depend on and may vary significantly with the operating radar system, operating wavelength, aspect angle, and polarization. Today, radar image analysis, interpretation, and exploitation is accomplished by trained image analysts. The training requires a long time and much effort. Modern radar systems are capable of collecting large amounts of image data which require more image analysts for timely and efficient analysis. Because experienced image analysts are in short supply a widening gap between data acquisition and data analysis has developed. The long range goal of this R&D effort is to develop fully automated capabilities for radar image analysis and exploitation. It is realized, however, that such a goal is very difficult to achieve and may take a long time. For that reason, the short term and intermediate goals consist of a series of developments, each dedicated to a specific stand-alone, fully automated capability that can be implemented in future systems. Such systems may include radar image exploitation stations, terrain analysis workstations, digital topographic support systems, and intelligence preparation of the battlefield capabilities.

APPROACH

The work towards the stated goals requires a thorough understanding of the following areas: dielectric properties of surface materials including vegetation and man-made objects; interaction of radar waves with surface materials; principles of synthetic aperture radar imaging; radar image analysis; terrain analysis; computer programming; computer image processing; and artificial intelligence. To be successful, a multidisciplinary team of specialists is required that includes for example radar image analysts, terrain analysts, physcists, electrical engineers, and computer scientists. Each specialist must be an expert in his own field, and must have a reasonable understanding and appreciation of the fields of the other specialists.

The features classes selected for automated extraction are assigned to three categories: linear features, area features, and special man-made features. Tables 2 through 4 show lists of the features classes being investigated.

Table 2

Linear Features

Boundaries
Canals
Dams
Pipe Lines
Power Lines
Railroads
Ridges
Rivers
Roads/Highways
Runways

Table 3

Area Features

Built-Up Areas
Deserts
Fields
Forests
Hills
Lakes
Mountains
Plains
Ponds
Swamps
Valleys

Table 4

Special Man-Made Features

Buildings
Bridges
Cloverleafs
Fences
Motor Vehicles
Parking Lots
PIERS/Dock Facilities
POL Storage
Radio Towers
Rail Yards
Transformer Yards

A large number of image samples of each feature class was investigated. The images were analyzed by expert image analysts. Various image processing techniques were applied to the imagery. Two knowledge-based expert systems were developed to support the feature extraction process. Computer software was developed on a VAX-11/780 computer and a Symbolics 3670 LISP machine using the C and LISP computer languages. In the following, several feature extraction techniques are discussed. These methods and techniques can be used to train and support image analysts and to be implemented in automated and interactive systems.

LINEAR FEATURE EXTRACTION

Linear feature on radar imagery can easily be recognized with the eyes. The lines are represented by sharp changes in gray tone, called edges, or as boundaries between area features. Examples of linear terrain features are boundaries, canals, dams, pipe lines, power lines, railroads, ridges, rivers, roads, and runways. Figure 1 shows a digitized radar image of an airport located near Elizabeth City, North Carolina. The digitized image consists of 512 by 512 pixels. The radar system to produce this image was the UPD-4. A smaller section (128 by 128 pixels) of image is shown in Figure 2 in pseudo-color. The smaller section comes from the lower central region of the original image, and consists of a portion of the airport's runway pattern. The first step in the automated feature extraction process is to transform the multi-level, digitized image into a binary image in which the edges of the runway have one value (bright) and the rest of the image has another value (black). The first step consists of the following image processing operations:

1. Edge preserving smoothing operation. The purpose of this operation is to smooth the image in such a way that sharp edges will not be blurred.
2. Edge enhancement operation that uses a Sobel operator to enhance pixels lying along an edge.
3. Iterative relaxation for edge reinforcement. This relaxation operation consists of a contextual technique in which the first and the second nearest neighbors of each pixel are examined to see if the pixel is actually a part of the edge. If it is decided that the pixel is a part of an edge then its gray level value is increased. After the relaxation operation is complete the image is binary. The runway edges have the maximum brightness while the rest of the image is black. The relaxation operation leaves the edges very thick and a final step of thinning is required.

4. The thinning operation consists of the application of several digital masks which analyze each bright pixel to see if it can be made black, without destroying any of the important geometry. The final result obtained after the thinning operation is shown in Figure . It can be seen that the edges of the runway pattern have a maximum brightness and the rest of the image is black.

The algorithms for each of the processing operations discussed above were written in the LISP programming language and run on a Symbolics 3670 LISP machine.

The next step is to perform measurements on the line structure of the binary image to determine the geometrical and topological characteristics of the feature. The characteristics are than represented as a symbolic expression. In the final step, the symbolic expression of the feature under investigation is matched against symbolic expressions stored in a knowledge-based expert system for classification and identification. The linear feature extraction process described above is only one of several technical approaches.

AREA FEATURE EXTRACTION

There are several procedures to automatically extract area features from radar imagery. The feature extraction techniques described below concentrate on the extraction of the four area terrain features: water, cities, fields, and forests. The SAR imagery to be used was taken over the Elizabeth City area. Approximately 200 SAR images were selected, digitized, and stored for the feature extraction work. Each digitized image consists of 512 by 512 pixels representing a ground area of approximately 1.6 square miles. Most of the images selected contain the four categories of area terrain features stated above and some linear terrain features such as boundaries, bridges, railroads, rivers, and roads. The algorithms for the automated feature extraction process were written in the LISP programming language and executed on a Symbolic 3670 LISP machine. Figure shows one of the digitized SAR images. It contains water, fields, forests, a township, and a road running from the top to the bottom of the image. The process of the automated extraction of the four area terrain features consists of the following steps:

1. Load the digitized image from the disk to the computer. The image shows in black and white on the display set.
2. Based on its gray tone level, each pixel of the image is assigned a pseudo-color depending upon its gray tone level for easy viewing.
3. A 3x3 Sobel operator is moved sequentially through the entire image for boundary detection and enhancement. The enhanced boundaries segment the image into larger regions. Although, the entire image is divided into four regions, none of the regions are smooth enough to be represented or displayed by a single color. In addition, the Sobel operation produced unwanted noise like spots all over the image.
4. In order to eliminate these black spots, a lowpass filter is passed through the whole image.
5. After the lowpass filtering, a technique called "region growing" is employed to smooth each area terrain region, so that the gray tone of all pixels of a given region will have the same value, and the region can be displayed by a single pseudo-color.

Recognition of these area terrain features can also be accomplished by using texture measurements and Bayes classifiers. The recognition results using this technique are also shown on Figure B with letter characters.

RADAR DESCRIPTORS AND DESCRIPTOR SETS

Radar images of a terrain feature class can be characterized by sets of descriptors. Descriptors represent primitive attributes of radar signatures. They are easily recognized and understood by untrained personnel. Descriptors lend themselves to measurements in the digital image domain using computer vision techniques. A set of descriptors is chosen so that it identifies the feature class unambiguously. The characterization of a feature class may require more than one set of descriptors.

A detailed examination of approximately 700 SAR images covering 29 classes of man-made and natural terrain features led to the identification of 52 descriptors. Each descriptor consists of attributes that are used by image analysts in their image interpretation. Table 5 lists the attributes to identify and define the 52 descriptors.

Table 5

List of Attributes of Radar Descriptors

Point
Line
Area
Number
Single
Group
Shape
Pattern
Linear
Compound
Bright
Medium
Dark
Fine
Coarse
Length
Width
Spacing
Orientation
Brightness
Rectangular
Rectilinear
Curvilinear
Bends
2 Parallel Lines
3-4 Parallel Lines
4 Parallel Lines
Parallel to Radar
Convex/Concave to Radar
Interlocking
Intermingled
Diameter
On-Line
No-Return

The descriptors including their attributes can be arranged into a hierarchical organization as shown in Table 6. Each descriptor is designated by a key consisting of two letters that are shown in the first column of Table 6. Descriptor and descriptor sets can assist personnel with little or no training to perform feature extraction from radar imagery. Image processing and computer vision techniques are being used in the development of descriptor extraction techniques. Once a descriptor set is extracted, an expert system can be used to identify the feature. A prototype of the expert system was developed and can be used in interactive feature extraction.

EXPERT SYSTEMS

Two knowledge-based expert systems were developed in support of the automated radar image analysis research. The first expert system is used as radar image classification aid (RICA) to improve textural feature extraction. The second expert system, called radar descriptor system (RADES), is used to determine the feature classification of a descriptor set.

RICA is an application of artificial intelligence techniques to the area of image processing. A Bayes Classifier is used to classify 32 x 32 pixel areas called windows in a synthetic aperture radar (SAR) image. Each window is classified as one of the four terrain feature classes city, field, forest, water, or as virtual border windows. Virtual border windows include true border regions between the area features city, field, forest, water and regions that are classified incorrectly. RICA identifies true border regions and eliminates false border classifications.

A feature is characterized by one or more sets of descriptors. The descriptors are arranged into a hierarchical organization and designated by keys consisting of two letters. Descriptor sets can be represented by Boolean expressions. The rules for the descriptor sets are incorporated in RADES. There are two ways to use RADES. First, the input to RADES are descriptors that are extracted from a radar image. If the descriptors belong to a feature descriptor set RADES will answer with the name of the feature. Otherwise, the answer is "unknown." Second, the input to RADES is the name of a feature. The answer of RADES is a list of descriptor sets that characterize the entered feature. If the entered descriptors do not exactly match a feature descriptor set, the answer of RADES are most likely feature names.

CONCLUSIONS

The development of automated feature extraction methods and techniques requires a multidisciplinary team. The solution of the long range goal of fully automated feature extraction may be found in the solutions of many individual tasks which require a wide range of technology. The individual tasks are building blocks towards the final goal and can be used as subsystems in existing and future interactive systems.

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