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Final Report

REMOTE SENSING FOR MATERIAL IDENTIFICATION UNDER SPACE UMBRELLA

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The objective of the Remote Sensing for Material Identification effort was to improve the understanding of the Foreign Aerospace Science and Technology Center (FASTC) in the exploitation of multispectral data. A one-week multispectral exploitation course, with emphasis on material identification, was prepared and conducted at ERIM's Ann Arbor facilities.

Follow-up consultation and support focused on a study to determine how current and planned ERIM multispectral exploitation software tools, with emphasis on change detection, could be migrated to planned FASTC systems.

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1.0 INTRODUCTION

Battelle is under contract (F33657-88-D-0076) to the Foreign Aerospace Science and Technology Center (FASTC) to provide support to FASTC's analysts in reviewing and assessing foreign science and technical information. In support of this effort, Battelle issued a subcontract to ERIM (Y-6852-1761) to perform a task entitled Remote Sensing for Material Identification (TAG No. 90-04D/Task Order No. 15). This document is ERIM's final report under TAG 90-04D.

The objectives of the task were: (1) to conduct a course for FASTC personnel to allow them to identify materials using civilian satellite multispectral data, (2) to provide a hardcopy of course materials to serve as a handbook of techniques, and (3) to provide on-site consultation as a follow-up to course conduct.

Multispectral imaging exploitation analysts at ERIM prepared and conducted a one-week course entitled Remote Sensing of Materials. A course handbook, consisting of the detailed viewgraphs used for the course as well as selected imagery materials, was provided to each student. A student survey was conducted to evaluate how well the course served the needs of the students.

Follow-up consultation focused on a change detection study to determine how best to migrate ERIM multispectral change detection capabilities to FASTC. ERIM multispectral and software analysts studied current and planned multispectral change detection capabilities within FASTC/DXH and reviewed existing and planned FASTC/DXH computer systems/platforms which could support multispectral change detection. Current and planned implementations of ERIM change detection software were evaluated against existing and planned FASTC/DXH change detection capabilities and potential host systems. Several candidate migration paths from ERIM to FASTC were evaluated with respect to feasibility, capability, compatibility, performance and migration cost/schedule/risk. The best migration path was described and a short-term support plan was identified which would provide FASTC/DXH with a capability to perform multispectral imagery restoration with their current systems.

Section 2.0 of this final report describes the Remote Sensing of Materials course, including preparation, content, conduct, and evaluation.

Section 3.0 of this final report describes the multispectral change detection study, including current and planned FASTC/DXH capability and systems, ERIM change detection software, and recommendations to FASTC/DXH.

2.0 REMOTE SENSING OF MATERIALS COURSE

2.1 COURSE PREPARATION

In November, 1990, ERIM received authorization to proceed on TAG 90-04D. Figure 1 shows the course outline as agreed to with the Government. The course was five days in duration. Each day was generally partitioned into a morning series of lectures and an afternoon series of laboratory exercises. FASTC/DXH provided background data on each student. This data was summarized by student, education, experience, and materials of interest, as shown in Figure 2, and provided to ERIM staff to guide in course preparation and conduct. ERIM staff and the Government interacted to identify a mutually agreeable date for the course.

2.2 COURSE CONDUCT

The Remote Sensing of Materials Course was conducted March 25-29, 1991 at ERIM's Ann Arbor, Michigan, facilities. Ten Government students attended and each received a handbook assembled during the conduct of the course. A summary of handbook materials is provided in Figure 3. In addition to the Remote Sensing of Materials handbook, the Government requested and ERIM provided five copies of The Infrared Handbook (Wolfe and Zissis).

2.3 COURSE EVALUATION

An informal course evaluation was conducted through interviews with approximately one-half of the students. This informal evaluation elicited a spectrum of student responses. A number of students gave a highly favorable evaluation of the course. For many of the students, the course was not as advanced nor as focused on material identification as desired. The general feeling among attendees was the course content did not completely meet the expressed needs of the group.

Student	Education	Experience	Materials/Interests
T. Hawley	BE Material Science	little imagery exploitation	General methodology/analysis tools
J. Bankovskis	PhD Aerospace Engineering and Applied Mechanics	little experience in multispectral imagery	metal and composites
N. Watters	BS System Engineering/Electrical option	5 years image processing	differentiating material classes (fiberglass vs. ceramics, e.g.)
A. Perry	BS Geography MA Geography BS System Engineering/Electrical option	5 years image processing (panchromatic, IR, multispectral)	metals, ceramics, fiberglass
F. Avila	BA Geography MA Physical Geography	5 years imagery analysis, mensuration, and exploitation of multispectral and panchromatic data	
J. Cothren	BS Mathematics	Air Force training in imagery interpretation	composties vs. metallics, wood, asphalt, concrete
J. Null	BS Mechanical Engineering (some graduate work)	some experience with optical, SAR, IR, and laser radar signatures	sand, rock, concrete, foliage, steel, aluminum, fiberglass, rubber, dialectrics, coatings
C. Ruff	BS Electrical System Engineering	2 years of imagery analysis and exploitation	
J. Querns	MSEE, concentration in Electro-optics	undergraduate work in image processing and pattern recognition; graduate work in optical detection, radiometry, and infrared technology	tarmac, wood, camouflage, radar absorptive materials, plastics, polymers
K. McGinnis*	BS Education (biology, chemistry, physics)	5 years of image processing on mostly panchromatic data; ERIM SAR course; some multispectral experience	camouflage, special metals (airframes)

* Although Mr. K. McGinnis responded to the original student summary, he did not attend the class and was replaced by SSGT John Labadan of DXHT.

Figure 2. Student Summary for Remote Sensing of Materials Course

Fundamental Concepts of Remote Sensing

Electromagnetic Radiation/Matter Interactions

Field Exercise: Radiometric Measurements

Optical Sensors

Thermal Sensors

Digital Data

Color Composite Images

SPOT Product Details

LANDSAT Product Details

Reflectance of Terrain Features

Agricultural Remote Sensing

Spectral/Spatial Image Enhancement

Categorization

Geometric Correction

Sub-pixel Analysis

Material Identification Papers

Thematic Mapper (TM) System Design, Sensor Characteristics, Orbit, and Coverage

Image Geometry and Terrain Interaction (SAR)

Applications of SPOT data for Urban Real Estate Investment Information Systems

Band Selection

SPOT Mission, System, and Related Specifications

Geographic Information System

Change Detection

Soil Identification

Automated Imagery Interpretation

Global Database

Figure 3. Material Identification Handbook

3.0 CHANGE DETECTION STUDY

Change Detection is the term used to denote a series of operations performed on image data collected at two different times which provides information on the changes in scene content between the imagery acquisitions. Change Detection can be applied to imagery collected with any sensing modality, but it generally refers to digital multispectral mosaic or image data.

The process of Change Detection involves a number of necessary pre-processing and post-processing steps:

1. Radiometric pre-processing. Correction of image data anomalies (e.g., missing scan lines)

2. Image analysis. Preparation of the image data to improve change detection (e.g., image enhancement or restoration)

3. Geometric correction. The two image sets are brought into spatial registration, either by warping one to the other or by warping both to a standard map or chart.

4. Radiometric correction. The two image sets are radiometrically balanced or normalized to each other.

5. Image manipulations: Operations performed on both image sets to improve the interpretability of change detection results (e.g., convert from row/column to geographic coordinates)

6. Change detection. A variety of techniques which produce change data sets from the processed imagery pair.

7. <u>Hard copy output</u>. Production of a variety of hard copy film or print annotated color composites.

Described below is the current Change Detection capability within FASTC/DXH as well as the candidate systems on which to host Change Detection software. ERIM's current and planned Change Detection capability is described and a recommendation is made for a plan to migrate ERIM change Detection software tools to FASTC/DXH. A short-term plan provides data to DXH so that current DXH systems can perform restoration of TM and SPOT data. A long-term plan draws on internal ERIM developments to produce a Change Detection software package compatible with the target FASTC/DXH computer environments.

3.1 CURRENT AND PLANNED DXH CAPABILITIES

DXH performs the bulk of their digital imagery processing on a system called IMAGES, developed specifically for DXH by International Imaging Systems (I^2S). While IMAGES is a robust digital image processing capability possessing some of the underlying tools necessary for Change Detection, IMAGES does not perform Change Detection per se.

The operational IMAGES capability is provided in an Imagery Display System (IDS) workstation hosted by a VAXStation 3200 running VMS and with an I^2S array processor (BITE), I^2S display (IVAS), and I^2S software.

DXH, along with most of FASTC, is transitioning its VMS applications to the UNIX operating system in general and the Sun Microsystems family of engineering workstations in particular. Moreover, the graphical user interface standard emerging across FASTC is the X-window system and the Motif window manager. Thus, the target environment at FASTC/DXH for any long-term Change Detection software is a Sun workstation running X-Windows and Motif.

3.2 ERIM CHANGE DETECTION CAPABILITY

Software developed by ERIM which is applicable to FASTC/DXH Change Detection requirements consists of the following capabilities.

1. Image Processing Facility (IPF) IAS-300-L software package, a complete image analysis, radiometric enhancement, and geometric correction software system.

2. PISCES Change Image/Reference Image, a capability layered on the IPF software package which produces change detection products from Landsat TM images.

3. Change Vector Analysis, an improved method for change detection incorporating multispectral change magnitude and direction information.

Each of these three analytical and software capabilities are summarized below.

3.2.1 IPF Software Package

The IPF software package IAS-300-L is a set of independent program modules that are executed in a multiuser operating environment. The independent program design philosophy of the IAS-300-L makes it totally upward expandable and allows it to be easily interfaced with other software modules. The IAS-300-L software runs on a VAX under VMS.

The IAS-300-L software package is partitioned into eight basic sections: Data Input, Interactive Display Operations, Radiometric Preprocessing, Image Analysis Techniques, Multispectral

Classification, Geometric Processing, Digital File Manipulations, and Output Products:

- Data Input. This software provides the means of generating disk image files from a variety of CCT image data formats. It also allows digitizing of map data and performing transformations between geographic and projection grid coordinates.

- Interactive Display Operations. These software modules permit user interaction with disk image files to extract training sets and ground control points.

- Radiometric Preprocessing. This software is included to correct image data file anomalies such as dropped scan lines or Landsat striping.

- Image Analysis Techniques. These software modules allow the analysis of disk image data and processing of the data by various filtering, algebraic manipulation, and statistical techniques.

- Multispectral Classification. This software provides analysis and processing of multispectral data to produce thematic data image files. Smoothing of the resultant data and area tabulations are also provided in this module.

- Geometric Processing. These software modules provide generation and application of correction coefficients to remove geometric distortions from satellite data. Correction techniques include affine, nonlinear, and rigid model nonlinear. Resampling techniques include nearest neighbor, bilinear, cubic convolution, and an ERIM proprietary deconvolution approach (Restoration).

- Digital File Manipulations. This software allows the generation and manipulation of disk image files. Manipulation techniques include merging of image files, mosaicking of geometrically corrected image files, radiometric balancing of image data during mosaicking operations, sectioning of image files, and vector to raster conversion of digitized map data.

- Output Products. The software in this section prepares disk image files for output and produces hard copy image products, typically on a precision film recorder. Included in this software are modules to optimize the response of the output device for various image products.

The software supports a variety of standard cartographic projections, for both map input and image file format.

3.2.2 PISCES Change Image/Reference Image

Landsat Thematic Mapper digital data from two dates (normally one year apart) is used in Change Image/Reference Image (CI/RI) to generate a set of color images consisting of a Thematic Mapper Change Image (TMCI) and two Thematic Mapper Reference Images (TMRIs). The TMCI combines data from the two dates to show changes that have occurred from one year to the other; it can be produced as a single full-scene image and/or as four separate quadrant images. Each TMRI is a composite of three bands from a single Thematic Mapper scene; it is produced as a full-scene image.

Each TMCI is formed from two multispectral images by color-coding the first-date image cyan and the second-date image red.

Areas that are "brighter" on the first date than on the second will appear in cyan tones, while areas that are "darker" on the first date than on the second will appear in red tones. Areas that have not changed from date to the other will appear in grey tones.

Some apparent changes, such as those caused by clouds, are unimportant and can be misleading to the interpreter. In order to diminish the impact of such changes, CI/RI incorporates algorithms, or rules, for screening and editing the images. "Screening" is the process of identifying specific categories, such as clouds and vegetation, in an image. "Editing" is the process of modifying an image based on the screening results.

CI/RI may be divided, conceptually, into six functions. these functions include spatial registration, screening, change image and reference image preparation, image composition, image annotation, and filming:

- Image Annotation: Annotation consists of text, lines, and subimages (such as tick marks) that are to be combined with images to form the final products. Major text and subimages include a scene title, image scale, latitude and longitude designations, a location map and a disclaimer.

- Spatial Registration: After manual selection of matching control points in the two scenes, regression techniques are used to warp the first scene to geographically match the second. Only the region of each scene that is common to both scenes is used in subsequent processing. The first scene is resampled in a computationally intensive process to allow pixels to line up between scenes so that they overlay exactly.

- Screening: The initial screening of the data begins by taking a systematic subsample from a scene (a pixel is selected every thirteenth element of every thirteenth row) called a scenelet. This is a representative sample and should contain all scene elements of interest. Scenelet data are automatically analyzed to generate initial screen statistics and are used to calculate default thresholds to be used with the final screen algorithm. The default thresholds are then reviewed with an interactive display program and refined as necessary. The refined thresholds are used to screen the entire scene.

- Change Image and Reference Image Preparation: Screened data (screened for clouds) are used if available. Normalization and contrast stretch coefficients for the change image and contrast stretch coefficients for the reference images (TM 3, 4, and 7) are automatically determined based on scenelets. The resulting high and low points used for data stretching may be interactively adjusted. The change feature, which is the basis for the change image, is then computed over the entire scene for each date. The adjusted scaling coefficients are applied to the full scene images (both change and reference) to prepare them for filming.

- Image Composition: The scaled change image is edited according to the final screening results. Editing sets the color of pixels identified as cloud on either date to white and tints pixels identified as vegetation in the second scene to green or grey. This editing is intended to minimize the confusion due to apparent changes caused by clouds or by normal vegetative development patterns. The nature of the editing performed depends on options selected at the beginning of data processing.

- Filming. Rasterized versions of the composed and annotated change and/or reference images are sent electronically to the film recorder and transformed into black and white separates. From the separates, either transparencies or prints can be produced. An option is available to film at any of several scales. This option allows quadrant format change images to be filmed in the same format (though different scale) as the full frame change or reference images.

3.2.3 Change Vector Analysis

Traditional change detection techniques are typically single band comparisons or spectral feature comparisons. Each of these change detection techniques has limitations. One limitation of the single band change image is that it does not show any terrain changes that do not have manifestations in the displayed spectral band. In addition, change images made with different spectral bands may show different results. Some limitations of single band techniques can be alleviated by creating change images from spectral features which are linear combinations of several or all of the individual bands. However, not all changes will show up well in any one spectral feature. One way to ensure that all radiometric changes are captured is through a technique known as change vector analysis. In this approach, a "change," or movement from one end point to another in multispectral change space, is characterized by a vector having both a magnitude and a direction [1,2]. The magnitude of a change vector is simply the Euclidean distance between the end points through n-dimensional change space. The change direction can be specified by whether the change is positive or negative in each channel. Thus, there is the potential to distinguish 2n types of change, rather than the 2 types possible with single band approaches [3].

The Multispectral Change Magnitude (MCM) image incorporates both the multispectral change magnitude and direction information available through change vector analysis. The MCM image is prepared by appending the change magnitude onto a base image and assigning color to the magnitude according to the change direction. A more interpretable type of direction color coded Multispectral Change Magnitude Image can be prepared by computing the change magnitude and direction in spectral feature space. For some applications of change detection, certain kinds of change are of no interest. Under these circumstances, some editing of the change image is supported. Editing of changed areas can be accomplished by setting their color to gray (i.e., appearing as no change), or by making them a unique color that can be disregarded. Identification of which pixels should be edited can be accomplished by examining the direction of the change, or by classifying either or both end points characteristic of the change. Change images can also be edited on the basis of the multispectral change magnitude. If the only changes of interest are those with a high change magnitude, then all changes that do not exceed a certain change magnitude can be suppressed (turned gray) [3].

Another type of change image is of the binary form, where all pixels meeting some specified criteria for change are set to a constant value representing change, and all other pixels are set to another value representing no change. This binary change information is merged into a background image so that the changed areas are displayed in a prominent color (red, e.g.) against the background [3].

A disadvantage of the above procedure is that all radiometric information from the background is lost when the changed pixels are turned red. A procedure that overcomes this disadvantage is to draw an enveloping polygon around the changed pixels, and to alter only the outline pixels. This procedure is supported with a software package called AGGREGATE to cluster the changed pixels into groups of spatially contiguous pixels, around which borders are drawn. In the change image only the borders of the changed areas appear, preserving the background information contained in the central portions of the changed areas. An additional advantage to this procedure is that the result can be edited on the basis of size so that small changes can be ignored. Editing small sized changes will remove individual pixel changes, many of which may be due to imperfect registration between the two dates [3].

3.3 ERIM MULTISPECTRAL DEVELOPMENT PROGRAMS

In recognition of the utility of an unclassified, broad area, and current data base of imagery to support mission planning, the U.S. Air Force (USAF) has established the ARC Digital Raster Imagery (ADRI) program. The image data bases generated under the ADRI program will be used in mission planning systems as an image backdrop to assist mission profile development, and to provide geopositioning and perspective view generation capabilities. Under Phases I and II of the ADRI program, ERIM produced the military specification for the ADRI product and generated prototype data bases of ADRI products over six geographic regions in Europe and the United States. ERIM is currently under contract to support Phase III of the ADRI Program. Specifically, ADRI Phase III calls for the processing of 3000 SPOT Panchromatic scenes (GIUs) into ADRI data bases. There is an option for processing an additional 2000 GIUs immediately following the initial production run of 3000 GIUs.

3.3.1 ADRI Requirements

The ADRI data bases are generated from Level 1A SPOT Panchromatic satellite images. SPOT Panchromatic images provide worldwide coverage at a resolution (10m) that is sufficient for most mission planning activities. SPOT data have the further advantage of being an unclassified source of imagery, and under the provisions of the USAF's license to acquire SPOT data, can be used on an unrestricted basis within the USAF for any aspect of the mission planning process including mission rehearsal, simulation, and intelligence support. Each SPOT image, or GeoImage Unit (GIU), covers a minimum surface area of 60 km and a maximum of 60 km by 81 km depending on the viewing angle of the High Resolution Visible (HRV) push-broom scanners used to collect the imagery.

Uncorrected Level 1A SPOT data are utilized as the input to the ADRI production process in order to take full advantage of: 1) a rigorous SPOT satellite model that is applied with ground control and tie points in a block adjustment over multiple images, and 2) the advanced restoration resampling technique that preserves the original radiometric and geometric fidelity of the acquired scene radiance. Individual SPOT images are geometrically corrected and orthorectified to the Equal Arc-second Raster Chart/Map (ARC) system utilized by the Defense Mapping Agency's ARC Digitized Raster Graphic (ADRG) standard product for maps and charts. DMA Level I Digital Terrain Elevation Data (DTED) are used to correct image displacements due to terrain relief. Multiple SPOT images are mosaicked and radiometrically balanced to form one-degree-by-one-degree data bases (Zone Distribution Rectangles, or ZDRs) of ADRI imagery.

The ADRI data bases are delivered on 8mm Tape Cartridge digital media in an output format that is directly compatible with the USAF's Common Mapping, Charting, Geopositioning, and Imagery

(MCG&I) System (CMS) developed by Rome Laboratory. The CMS provides the USAF with a capability for data preprocessing, configuration management, and distribution of MCG&I data and is the vehicle to port ADRI data to all mission planning systems.

3.3.2 ERIM Remote-Sensed Image Processing Software

With the near-term goal of supporting ADRI production, ERIM has plans for development of a workstation system to support both internal and external sponsors. The reader should view these plans with the understanding that significant modifications could occur at any time.

ERIM is currently developing the next generation implementation of its software for exploiting literal image remote sensed data. The software, which has a long history of creating high quality image products from data sources such as Landsat TM, SPOT, and others, is being moved from a VAX/VMS environment into the UNIX workstation environment. The process is a combination of porting and repackaging in which the algorithm is kept intact while being placed in a new software system. The new system has a design and user interface which is tailored to the capability of modern multiwindowing workstations. Some notable features of the system include:

a. Full integration of display capabilities with algorithmic applications;
b. Integration of separate processing steps into functionally complete applications;
c. Complete support for graphical, prompt, and command line user input;
d. Distribution of processing and display load by incorporating a network of workstations with high resolution displays.

3.3.2.1 Design Goals

The four primary design goals for this project are:

a. Maintain the breadth and quality of products which are produced in the current VAX based implementation;

b. Maximize portability between UNIX workstations;

c. Maximize the operational efficiency of the user; and

d. Create a system which can be easily customized for special-purpose clients.

3.3.2.2 Hardware Environment

The system is designed to operate on either stand-alone or networked UNIX workstations. Networks of workstations may contain a mix of supported makes and models, and may have some nodes with unique capabilities such as digitizers, filmwriters, or multiple CPUs to support specialized tasks. The user may access the workstation via the high-resolution console, an X-terminal, or a standard ASCII terminal. The console offers complete access to all system functions and high display quality. X terminals can be used to run any application, but display quality suffers for multiband images and display speed is diminished. An ASCII terminal can be used to run any application with complete user interface support, but line graphics and image display cannot be used. Applications may also be run batch.

Use of a network of workstations is a key component in optimizing throughput for large installations. The operational efficiency of a number of self-contained units which can communicate with each other is far greater than alternatives, such as a mainframe with multiple display devices or a large workstation supporting multiple X terminals. This operational efficiency is a product of the following factors.

a. Increased system I-O bandwidth;

b. Reduced data transfer over the network;

c. Distribution of processing among CPUs; and

d. Decreased resource contention among users.

The first platform for which this system is being developed is Silicon Graphics workstations. It was chosen for its superior display support (16 simultaneous 8 bit lookup tables, 24 bit direct RGB mode, and annotation hardware) and the wide range in performance available in the product line (up to 77 MFLOPS). Development is taking place on an IRIS 4D-30, a machine with CPU speed comparable to a SPARC2 (4.7 MFLOPS) and with the display capabilities listed above. Implementation on SUN and HP is planned after completion of the Silicon Graphics implementation. Porting to the SUN and HP will involve recompiling and testing all code and conversion of a small section of the display utility to X windows.

3.3.2.3 Software Architecture

The system consists of a set of applications. Each application is a separate executable program. Multiple applications or multiple copies of an application may be run simultaneously. The structuring of the system into separate applications assists in making the system customizable for special-purpose users.

Each application contains three components:

a. The algorithm subroutines;

b. The application driver; and

c. The utility packages.

The algorithm subroutines contain the code which is the heart of the processing which has been performed on the VAX. These subroutines have been extracted from the programs which originally contained them to provide a library of high level image processing functions which are callable by applications. This allows applications to perform a combinations of highly complicated image processing procedures by making a series of subroutine calls.

The algorithms to be included in the system include:

a. Data loading - tape reading and format decoding for SPOT, TM, MSS, etc.
b. Registration and resampling - polynomial resampling algorithm with specific models for each major sensor
c. Multiple image algorithms - mosaicking, change detection, data fusion, perspective view
d. Filters and transforms
e. General image processing utilities - section, combine, histogram, etc.

The application drivers perform all user interface and provide the algorithm subroutines with all necessary data. This includes displaying input and output images, enabling user interaction with the images, and collecting more conventional inputs. The application drivers are designed to both lead the user through the required steps and allow flexibility of use for the experience user.

The drivers are created using a package called SET (Software Engineering Tool) by CASET Corp. This package facilitates the development of complex user interfaces by allowing applications to be defined as Finite State Automata (FSAs). An FSA consists of one or more sets of states, transitions, and actions which define all possible paths through the application, what causes the path to be taken, and what actions are performed in the process. Once the program flow and command structure has been defined in the notation provided by SET, it provides tools to create a graphical user interface. Both the graphical and text based interface are always available to the user. The text based interface provides a rich set of user customization capabilities, including macro recording and playback. SET also provides an environment in which customization of the applications can be performed easily. The SET software is currently being enhanced by the vendor to provide the graphical user interface with the look and feel of MOTIF.

The utility packages contain callable routines to support

a. Image I-O
b. Non-image I-O
c. Processing history recording
d. Plotting
e. Shared memory usage
f. General purpose math and utility functions and
g. Image display

Of the utility packages, the display package provides the functional capabilities which are unique to the system. The display package is a high level client-server system which supports multiple image display with full interaction from applications and the user. Each image display allows access to the full image, regardless of image size. Applications may even share display windows to make maximum use of system resources and minimize start-up time.

The frequent use of simultaneous multiple image displays has led to the development of a default screen layout for images. This default screen layout allows all active images to be visible and accessible in small windows with selected image (s) in the main display area. The main display area supports split screen/tiling of up to 12 images. The default screen layout can be overridden by the user.

The user is always provided access to functions to control the display windows, even when the application is in the midst of a long computational sequence. These control functions are accessed through either the Display User Interface window or in the actual image display windows. The Display User Interface provides functions which are not speed critical, involve more than one image, and do not depend upon cursor positioning within the image. The functions provided in the actual display window are those which are highly interactive or depend upon the cursor position.

Functions available in the image display windows include:

a. Variable speed image scrolling in any direction;
b. Mouse directed image panning;
c. Zoom/dezoom for zoom factors of 1 or more;
d. Cursor position readout;
e. Annotation display/no display toggle;
f. Cursor shape toggle; and
g. Window resize and other window management functions.

Functions available in the Display User Interface include:

a. Screen layout/tiling control;
b. Zoom/dezoom by any zoom factor;
c. Annotation control (image corner positions, cursor readout, etc.);
d. Lookup table control (read, write, graphical edit);
e. Image positioning (move to row and column);
f. Coordinated image movement (two or more images pan or scroll synchronously) and
g. Coordinated lookup table control.

The display package provides a set of capabilities which can be invoked by applications. The display server and the application "talk" to each other. The application requests that a command be performed, and the display server returns the results of the command to the application.

Capabilities available to applications include:

a. Creation of a display window for an image
b. Region of interest functions - user selects or edits a point, box, polyline or polygon
c. Image positioning - pan to a specific row and column of the image
d. Image and annotation color/greyscale mapping
e. Annotation display and deletion
f. Deletion of a display window for an image.

The high level client-server design of the display utility gives the following benefits.

a. The user may ALWAYS interact with the image, even if an application is the middle of a long computational session.
b. Applications can communicate with the display in a high level fashion, i.e., the application calls a subroutine to ask for a polygonal region, the display allows the user to pick it on the image and returns the results to the application through the subroutine.
c. Display environment specific code is localized to the display server allowing a high degree of portability. Even changes in industry standards result in only a small change to the system and the change is isolated from the algorithms.

3.3.2.4 Schedule and Development Plans

The initial focus of this development effort is to support the creation of mosaics of panchromatic SPOT images in support of ADRI. This development phase is scheduled for completion in June 1992. During the summer of 1992, development will shift to supporting TM data and additional algorithms which make use of this data. At this point, the display capability will be expanded to work with multiband data. The remainder of 1992 and the first quarter of 1993 will be spent developing support for MS and other scanners. After completion of this stage, all capabilities will be intact on the Silicon Graphics platform. At this time, the software will be ported to SUN and/or HP platforms and support for the X window system will be added to the image display system. The SET user interface already supports a large number of devices and windowing systems, including X windows. Hence, the porting effort for applications will consist of recompiling, testing, and correcting for platform specific dependencies. Release on an X windows-based platform is anticipated for late summer of 1993.

Because of possible changes in the business area, new hardware/software developments and funding limitations, development activities after June 1992 (ADRI) are only a tentative committment. Re-evaluation after that point could cause significant modifications to the development plans. The reader is therefore warned that significant modifications to hardware/software and development plans could occur after June 1992. This new ERIM remote-sensed image processing software is anticipated to be ERIM Proprietary commercial off-the-shelf (COTS) software.

3.4 RECOMMENDATIONS

ERIM recommendations for the migration of ERIM multispectral tools to FASTC/DXH are provided below.

3.4.1 Restoration Resampling

Exploitation of multispectral data invariably involves the resampling of digital multiband imagery. The resampling methods common to commercial digital image processing packages act as an added convolution, or blurring, of the image, which has important implications for the spatial frequency content of the image [14]. In particular, nearest neighbor resampling is equivalent to convolution with a rectangle function and bilinear interpolation is equivalent to convolution with a pyramid shaped function [2; 18]. Both suppress the higher spatial frequencies leading to loss of resolution in the reconstructed image. The parametric cubic convolution interpolator preserves more of the higher frequencies but can exhibit ringing near edges. Cubically convolved imagery still has a somewhat blurred appearance compared to unresampled imagery.

A resampling method called "restoration" or "deconvolution" attempts to recover losses suffered in the image due to the imaging process itself [4; 20; 21]. The grey level value assigned to a particular pixel in an image is the result of averaging or integrating information from a neighborhood of ground radiance values [7]. This blurring effect is inherent to all imaging systems and can be described in terms of the system's point spread function, or impulse response function, which characterizes the irradiance distribution at the image plane of an object which is an ideal point source. A detailed knowledge of the system's point spread function can be used as a model from which to make linear combinations of pixels and their neighbors so that a new point spread function can in effect be synthesized which can approach a resolution limited by the original sampling interval. Restoration is different from other resampling methods, which are attempts to reconstruct the original image before sampling, rather than the scene from which the image was derived.

Using restoration for resampling would boost, rather than suppress, those frequencies which had already undergone some suppression in the imaging process. The idea is to use a restoration filter as the resampler to account for blurring that had already occurred, rather than to introduce more blurring (high frequency suppression) in the image. The approach is designed to predict the radiance value that would have been obtained using a sensor with a more desirable point spread function positioned directly over the location for which a value is desired [4]. The result of restoration resampling is a sharper image with greater information content [7]. Restoration has been shown to give better classification results than other resampling methods under certain combinations of blur and noise [8]. Resolution can be improved in along-scan Landsat Multispectral Scanner (MSS) data from an effective instantaneous field of view of 86 meters to one of 58 meters [16]. (It is important to note, however, that the effective instantaneous field of view is only one of many measures of resolution and does not account for such degrading artifacts as noise enhancement and edge grey level overshoot. Also, the presence of the nonlinear Butterworth filter in the sensor's along-scan direction makes for more potential resolution improvement than could be expected along-track where the filter is not used.) Restoration requires about the same amount of computer time as cubic convolution.

Restoration must not be confused with edge enhancement which is basically a heuristic procedure designed to enhance visual discrimination of features. Restoration also enhances edges, but it does so in a physically meaningful way which results in less radiometric error. Restoration enhances edges by removing known blur while minimizing the radiometric error.

Restoration is possible because typical satellite sensors have sampling rates (the number of samples per instantaneous field of view) greater than one. For the MSS there are 1.31 samples of the 63-by-63 meter ground projected instantaneous field of view along-scan and 0.93 samples along track. However, the imaging process itself degrades the image further. For instance, although the ground projected instantaneous field of view for MSS is 63-by-63 meters based just on the scanning aperture, the image-forming optics and electronic filter increase it to 77-by-65 meters (the filter is effective only along-scan). Sample scene phasing increases it to 86-by-122 meters and bilinear resampling increases it even further to 104-by-148 meters [11]. For the Landsat Thematic Mapper, analysis of imagery yields an effective instantaneous field of view of between 40.8 and 48.6 meters, compared to the published 30 meter resolution corresponding to just the ground projected detector size and 33.8 meters based on complete system modeling [5; 11]. Image-derived measurements take into account all the sensor blurring effects as well as atmospheric effects and cubic convolution resampling for geometric correction. (Presumably the difference in image-derived resolutions is due to shadowing and atmospheric differences.) For the SPOT panchromatic band, optics, uniform motion and crosstalk reduce the effective ground projected resolution to about 15-by-15 meters, rather than the published 10-by-10 meters. These combined effects conspire to produce redundant information from pixel to pixel which can be exploited using restoration techniques, since the blur added by these components effectively increases the sampling rate. For SPOT, resolution can be meaningfully increased by about 50 percent. For systems which are truly undersampled, restoration would reduce to interpolation, but the interpolation weights would be chosen based not just on the distance from surrounding pixels, but also on the shape of the point spread function.

Degradations accounted for in modeling sensor systems for restoration usually include sensor parameters such as those describing the optics and electronic filters, but may also include motion blur, atmospheric effects and ground processing. Thus, unlike the other resampling methods, restoration is sensor dependent and possibly even acquisition dependent. However, since no real physical system can be inverted exactly, noise enhancement can occur when the restoration is pushed toward its theoretical limit. The major drawback for restoration, though, is that it requires a thorough understanding of the sensor design and a mathematical model of the sensor's point spread function based on detailed engineering specifications. Thus it requires a major development commitment. The model only needs to be developed once for each sensor though (unless atmospheric or other time varying effects are to be accounted for) and once made the associated resampling coefficients can be used on all images derived from that sensor.

There are many approaches to restoration. Andrews categorizes them into four areas: a priori knowledge, a posteriori knowledge, signal processing and numerical methods approaches [11]. The success of any approach depends on how badly the image is degraded, how well the degradation is modeled, the amount and type of noise in the image and how the noise is dealt with, and how effectively the deconvolution is implemented. The particular approach used depends on how much and what type of information is available, the type of imagery being processed, the source of the degradation and underlying assumptions about the physics of the phenomena. Some approaches which have been used include maximum likelihood and maximum entropy [5], Bayes theorem [13], homomorphic filtering [10], Wiener filtering [12], constrained least squares filtering [6] and linear least squares deconvolution [4].

The approach used at ERIM is the linear least squares deconvolution approach [4]. The restoration (or deconvolution) process is performed as a linear filter acting on the original data. The coefficients are chosen so that the difference between grey level values produced using the correctly located desired point spread function and those produced using the linear filter approximation are minimized in a least-squares sense. This process has been shown to produce image data with higher radiometric fidelity than can be achieved with cubic convolution [17].

As a short-term measure, ERIM recommends that we provide data to DXH so that coefficients can be created and restoration of TM and SPOT data can be done by employing the convolution filtering capability of IMAGES. Documentation and training should also be provided.

3.4.2 Change Detection

The planned evolution of ERIM's multispectral processing software in general and the Change Detection capability in particular appears to be consistent with the system environments envisioned in the future within DXH. We recommend that a joint review be conducted in the spring of 1992, when ERIM will be close to a product announcement and DXH will have insight into the demand for multispectral change detection and will have an update on target systems and environments.

4.0 REFERENCES

1. Andrews, H. C., "Digital Image Restoration: A Survey," IEEE Computer, 7, pp. 36-45, 1974

2. Billingsley, F. C., "Data Preprocessing and Processing," in Manual of Remote Sensing, 2nd Ed., Chapter 16, American Society of Photogrammetry, 1983

3. Colwell, J. E. and F. P. Weber, 1981, "Forest Change Detection," Proceedings of the 15th International Symposium on Remote Sensing of Environment, ERIM, Ann Arbor, Michigan

4. Dye, R. H., "Restoration of Landsat Images by Discrete Two-Dimensional Deconvolution," Proceedings of the 10th International Symposium on Remote Sensing of Environment, pp. 725-729, October 1976

5. Freiden, B. R., "Restoring with Maximum Likelihood and Maximum Entropy," Journal of the Optical Society of America, 62 pp., 511-518, 1972

6. Hunt, B. R., "The Application of Constrained Least Squares Estimation to Image Restoration by Digital Computer," IEEE Transactions on Computers, 22 pp., 805-812, 1973

7. Kalman, L. S., "Comparison of Cubic Convolution Interpolation and Least-Squares Restoration for Resampling Landsat MSS Imagery," ASP Annual Meeting 51st, 2, Falls Church, VA, pp. 546-556, March 1985

8. Lai, D. C., J. Potenza and K. Verfaille, "Evaluation of Image Restoration Filters for Machine Classification," Optical Engineering, 23, pp. 794-800, 1984

9. Malila, W., "Change Vector Analysis: An Approach for Detecting Forest Changes with Landsat," Proceedings of LARS Symposium on Machine Processing of Remotely Sensed Data, 1980

10. Oppenheim, A. V., R. W. Schafer and T. G. Stockham, Jr., "Nonlinear Filtering of Multiplied and Convolved Signals," Proceedings of the IEEE, 56, pp. 1264-1291, August 1968

11. Park, S. K., R. Schowengerdt and M. Kaczynski, "Modulation-Transfer-Function Analysis for Sampled Image Systems," Applied Optics, 23, pp. 2572-2582, 1984

12. Pratt, W. K., Digital Image Processing, Chapter 14, Wiley, NY, 1978

13. Richardson, W. H., "Bayesian-Based Iterative Method of Image Restoration," Journal of the Optical Society of America, 62, pp. 55-59, January 1972

14. Schowengerdt, R. A., Park, S. K. and Gray, R., "Topics in the Two-Dimensional Sampling and Reconstruction of Images," International Journal of Remote Sensing, 5, pp. 333-347, 1984

15. Schowengerdt, R. A., C. Archwamety and R. C. Wrigley, "Operational MTF for Landsat Thematic Mapper," Proceedings of the SPIE: Image Quality, 549, April 1985

16. Schowengerdt, R. A. and L. Wood, "Image Deconvolution/Resampling Capability," Final Report to USGS EROS Data Center under contract number 14-08-001-22361, July 1986

17. Shah, N. J. and C. L. Wilson, "Multispectral Data Restoration Study," Bendix Aerospace Systems internal report #BSR4246, 1977

18. Schlien, S., "Geometric correction, registration, and resampling of Landsat imagery," Canadian Journal of Remote Sensing, 5, pp. 74-89, 1979

19. Virag, L. A. and J. E. Colwell, "An Improved Procedure for Analysis of Change in Thematic Mapper Image-Pairs, Proceedings of the 21st International Symposium on Remote Sensing of Environment, ERIM, Ann Arbor, Michigan, 1987

20. Wood, L., Restoration for Sampled Imaging Systems, PhD Dissertation, University of Arizona, December 1986

21. Wood, L., Schowengerdt, R. A. and Meyer, D., "Restoration for Sampled Imaging Systems," Proceedings of the SPIE: Applications of Digital Images Processing IX, 697, pp. 333-342, 1986