Highlight

Operational Multispectral Information Extraction: The DLPO Image Interpretation Program

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In 1993, the Defense Landsat Program Office (DLPO) initiated a research and development program to field operational multispectral data processing and image interpretation capabilities. This effort yielded highly automated software applications for thematic product generation and processing, some of which represent technological breakthroughs in multispectral image processing. Twelve applications were developed; two were deployed operationally, four are ready to be deployed, and the remainder are in various stages of maturity. Research was initiated to adapt some of these applications to the planned commercial high resolution multispectral systems. This article is a compendium of the image interpretation software and research projects initiated by the DLPO.

The DLPO was established under the Land Remote Sensing Act of 1992 (Public Law 102-555). Its image interpretation program was designed to address portions of the law "to continue and enhance programs of remote sensing research and development." The result is a comprehensive image interpretation program to maximize information extraction from Landsat Thematic Mapper data with an emphasis on operating in a production environment. The program emphasized geometric, radiometric and thematic accuracy in the generated products as well as automation.

A combination of funding disputes with NASA, failure of the Landsat 6 launch, and budget pressure within the Department of Defense brought about the termination of DLPO in June 1994. The image interpretation and utility programs which started under DLPO were transferred to its parent organization, the Office of the Secretary of the Air Force. The image interpretation and research program continued until Fall 1996.

The MAGISTIC Program: Image Interpretation and Production

The image interpretation program is called MAGISTIC which stands for "MATRIX Geographic Information System Turnkey Imaging Capability." The MAGISTIC program has four principal goals: 1) to provide a community-wide capability to exploit multispectral data from current and future multispectral collection systems; 2) to develop a standardized, interoperable software environment for multispectral image interpretation that is acceptable throughout the community; 3) to provide advanced technology to better and more efficiently use multispectral data; and, 4) to promote the use of multispectral data as a viable source of information to complement data from other existing systems.

Many of the program goals are addressed by the standards set for applications development. A government-developed softcopy exploitation package, MATRIX, was adopted as the development interface system. It is founded on Unix/X-Window/Motif/C/C++, thus maximizing integration into commercial hardware and software. All DLPO developers were provided with a copy of MATRIX software, which enabled developers to access available capabilities, and create software that had a consistent interface, followed a set of software programming guidelines, and adhered to a set of software system standards. In addition, this approach to software development provided immediate capabilities to government users at the end of the development cycle. MATRIX has since become an operational system with its own government-managed operations and maintenance. Through the operational MATRIX program, delivered software can be maintained and supported for users requiring the capabilities who cannot independently fund custom software development. In addition, the MATRIX software provides a large selection of data input and output options and basic image manipulation tools.

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Two development paths were initiated to achieve pioneering research and standardized production. One path was a high volume production component that provides an immediate, image product capability allowing users with minimal training to consistently produce standardized high quality image products on standard commercial off-the-shelf (COTS) equipment. This production component includes Common Product Generation, an image production system which guides a user through the production of nine image products, and Tiered Product Generation, a mission planning tool for pilots.

The other path was a research and image interpretation program. The program is designed to develop automated software for change detection, lines of communication extraction, terrain classification, and bathymetric mapping. To facilitate the automation of these tasks, several data preparation algorithms were developed as separate research and development efforts. These include geometric correction, automatic co-registration, atmospheric correction, radiometric balancing, and panchromatic and Thematic Mapper thermal band sharpening. All of these processing and image interpretation applications emphasize automation and streamlined production. This dramatically reduces the training and image-processing/remote-sensing experience required by analysts. The more complex programs, such as atmospheric correction and automated change detection, provide additional menus for more experienced analysts who wish to customize a complex process.

The next section presents an overview of the image interpretation projects developed under MATRIX and the subsequent section will provide an overview of the production system developed using a COTS package.

Research and Image Interpretation Program

The image interpretation program was designed to advance the state of the art in multispectral image interpretation capabilities. Contracts were awarded, following competitive source selections, to companies that were world leaders in different aspects of image interpretation; experts from government, industry, and academia often have been included on the development teams. As a result, the image interpretation program developed unique quantitative and automated capabilities that advanced information extraction from digital multispectral imagery.

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Each of the MAGISTIC applications are discussed. The first five projects, geometric correction, atmospheric correction, in-scene luminance normalization, panchromatic sharpening, and Thematic Mapper thermal band sharpening are data preparation applications. The next five projects—automated terrain categorization, interactive change detection, automated change detection, automated lines of communication extraction, and bathymetric mapping—produce thematic products. Accuracy assessment was developed as a separate project as it is still a research topic in the fields of remote sensing and GIS. The accuracy assessment discussion describes the effort under way to develop accuracy metrics for each of the thematic products so that operational users can combine thematic products into information products and have some measure of confidence in the accuracy of the information.

Geometric Correction and Co-registration

Geometric accuracy is one of most important issues in the use of satellite data for operational applications. Locational accuracy requires precise knowledge of the spacecraft orbit and sensor, and Earth's curvature and surface relief. The image co-registration module (COREG) was designed to provide precision geocoding of a Landsat scene and automated co-registration of two Landsat scenes of different dates. It also was designed to expand to include other sensors as needed.

COREG has three functional elements which incorporate the Landsat Thematic Mapper orbit and sensor models, and Earth curvature and relief models. It geocodes a Landsat TM image using ground control points (GCP), orthorectifies the image if a digital elevation model (DEM) is available, and co-registers it with a second image of the same region if available (Bult *et al.*, 1994). The transformations for each of these steps are combined and implemented in a single resampling of the image, thus minimizing degradation of spectral fidelity.

The co-registration module has an automated and a manual mode. The application screens for clouds and blackfill areas prior to initiating the automated tiepoint location algorithm. Correlation surfaces of the two images are checked for saddle features, boundary peaks and low surface curvature peaks, and tiepoints are selected by size of the correlation coefficient. Outlier tiepoints in the surface are eliminated by checking the image acquisition model and computing a measure of goodness. Through this process, tiepoints of questionable reliability are eliminated.

The presence of clouds or haze in one or both scenes of an image pair can impact the algorithm's ability to locate adequate tiepoints automatically. In scenes for which adequate quantity and dispersal of tiepoints cannot be located, the system will advise the user to activate the manual mode. In the manual tiepoint selection, the user selects tiepoints in each image at a pixel level, and the software refines the selections to a sub-pixel level by analyzing the correlation surface. Error statistics are generated to determine the surface fit to the model.

Orthorectification, when an elevation model is available, is fully automatic. Currently, ground control points for geocoding are manually selected in the same manner as in the manual co-registration mode.

COREG is designed, however, so that in the future a GCP library can be used instead. In addition, since the geocoding algorithms are integrated into MATRIX, the user can exercise the MATRIX mensuration functions for location (in lat/long and UTM), distance, and areal measurements.

Atmospheric Correction

Accurate atmospheric correction is essential to the automation of information extraction algorithms because it minimizes the effect of one of the largest contributors to variability in remotely sensed imagery. DLPO sponsored an Atmospheric Correction Workshop in June 1993 (Slater and Mendenhall, 1993) designed to assess the state-of-the-art of atmospheric correction and to recommend promising research directions. The focus of papers presented were techniques that compensated for atmospheric effects in multispectral imagery. Papers were presented in six research areas: atmospheric characterization; atmospheric radiative transfer models; scene-based correction techniques; thermal infrared techniques; multi-temporal techniques; and image processing and statistical techniques. The workshop was moderated by a team of specialists who reviewed the presentations and provided the program office with a summary paper that assessed the state-of-the-art of atmospheric correction techniques, recommendations for developing an atmospheric correction technique that was suitable in an operational environment, and listed the most promising research directions that would yield improvements in understanding and correcting for atmospheric effects. The recommendations were used by the DLPO to define the requirements and critical issues involved in developing a multispectral atmospheric correction program. The program includes data collection, algorithm development and validation, and fielding a multispectral atmospheric correction application.

ATM, a Landsat multispectral atmospheric correction application, was developed from the workshop committee requirements. ATM has two modes of operation: an automated mode that provides reasonable defaults for all of the required parameters, and an interactive mode which provides the user with several layers of menus for custom operation. Users with limited expertise may use default settings, while those with in-depth knowledge of the physical models or have ancillary data available have control over the parameters and correction process.

In the automated correction mode, all parameters are provided by ATM defaults. The user may customize the program via four menus: 1) scene acquisition parameters, 2) TM bands to correct, 3) atmospheric model parameters, and, 4) reflectance correction limits. The scene acquisition parameters menu provides the user with access to the calibration gains and offsets of the six TM reflective bands. The atmospheric model parameters menu has six sections: 1) molecular composition, 2) aerosol composition, 3) water vapor content, 4) ozone content, 5) average elevation above sea level (for the entire scene), and, 6) aerosol optical depth. Molecular composition, which provides the user with a selection of climatic types, is used to scale default values for atmospheric presence of water vapor and ozone. The default values for water vapor and ozone were derived from a table of their respective values as they vary by month and latitude. When more precise information is available, the user can modify the default. The aerosol composition indicates the amount of dust and other particulate matter in the atmosphere over continent or sea and can be adjusted by the user. The aerosol optical depth is a measure of the atmospheric haze. The ATM default is to use the 5S model for calculating standard aerosol. 5S was originally developed by Laboratorie D'Optique Atmospherique, Lille, France. The implemented 5S code includes modifications by Canadian Centre for Remote Sensing (CCRS) and University of Arizona researchers to specify elevation and sensor altitude (Teillet, 1994). The user has four other options: subjective visibility, meteorological visibility, measured aerosol optical depth, and dark target subtraction. The dark target technique assumes that the atmosphere makes up the bulk of the signal reaching a sensor from a dark object on the Earth's surface. This technique allows the user to correct the first three TM bands only.

The application's architecture was designed to incorporate readily planned enhancements such as elevation, surface geometry, water vapor, user-identified target spectra, multi-temporal matching, spatial inhomogeneity, cloud detection, and shadow detection and compensation. The current program does not correct for spatially varying atmosphere across the image nor does it compensate for terrain.

In Scene-radiometric Balancing

This project was designed to develop a basic luminance correction capability to normalize two Landsat Thematic Mapper images in support of image interpretation activities such as change detection and lines of communication extraction (Lawler-Covell *et. al.*, 1996). Images are empirically normalized using analyst- selected in-scene targets of known or presumed reflectance. The target spectra are drawn from a spectral library of common terrain classes. The scene is then corrected for the differences in reflectance between the image target and the spectral signature using a linear model which estimates the radiative absorption and scattering. This software has been expanded to work with 1 meter 4 band multispectral data such as Positive Systems ADAR 5000 imagery.

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Panchromatic Sharpening

The spatial resolution of multispectral imagery can be increased by fusing it with co-registered, higher spatial-resolution panchromatic imagery. Several techniques have been published in the literature to merge data from different sensors including Hue Saturation Intensity (HSI) (Welch and Ehlers, 1987), Principal Components Substitution (PCS), and High-Pass Filter Methods (H-PF) (Chavez and Bowell, 1988). However, most sharpening techniques fail to maintain spectral fidelity (Patterson and Bullock, 1994).

The Automated Spectral Image Sharpening Technique (ASIST) application sharpens the first four Landsat Thematic Mapper bands with a co-registered panchromatic image from either SPOT or the Landsat-7 ETM (Patterson and Bullock, 1994). The application was designed so that other sources of panchromatic imagery can be utilized; however, only multispectral bands whose spectral bandpass overlaps the panchromatic image bandpass can be sharpened.

ASIST can be directed to maintain either spectral fidelity or color balance in the sharpened product. The spectrally accurate product takes into account the design of the imaging sensors, and the spectral overlap of the bands being merged. The output of the spectrally accurate product is designed for spectral analysis and further exploitation. The second approach generates a merged product that emphasizes balancing the color of the output product. This technique assumes that the spectral overlap between the merged bands is perfect. Histogram stretching is performed on the output image to improve perceptual quality. The color balanced output is designed for human analysis and interpretation rather than automated interpretation.

Thematic Mapper Thermal-Band Sharpening

Thematic Mapper (TM) studies have shown the importance of TM band 6 in land cover classification (Toll, 1985) in general and the separability of agricultural cover types in particular (Kumar and Silva, 1974). Morgenstern *et al.*, (1977) have shown that the spatial resolution of TM6 was detrimental to performance in crop surveys. When acquired at the same spatial resolution of the other TM bands, it was found to be highly useful for crop discrimination. Thermal studies of urban and industrial regions also suffer from the poor resolution which is much coarser than the scale of facilities and their impacted surroundings. For these reasons, research was done to develop a technique to sharpen the 120 m TM thermal band using TM's other 30 meter reflective bands.

An adaptive image sharpener technique was developed to provide the framework for fusing imagery from highly disparate sources and scales (Iverson and Lersch, 1994). A multi-resolution Laplacian pyramid is iteratively constructed from the input data. The image pyramids feed a neural network which generates a predictive transform used to generate a high resolution version of the respectively lesser resolution images. This algorithm has been developed into a MATRIX application called Sharpen_TM6. The application sharpens the 120 m thermal band to 30 m resolution using all six of the 30 m reflective bands.

This technology has considerable potential yet to be tapped. There are no restrictions on the source imagery fused beyond the need for predictable correlations between them. Therefore, imagery with diverse numbers of bands, bandpasses, spatial scales, and collection geometries potentially can be fused to yield a product with the best characteristics of both image sources. In the near future, a variety of high spatial resolution multispectral and panchromatic satellites will be launched into orbit. This technique will be readily adaptable to fusing these sources with each other as well as with other lower spatial resolution and hyperspectral imagery.

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Mystic: Automated Multispectral Land Cover Classification

Land cover classification maps are a crucial component for a wide variety of commercial, civil, and military applications. These maps (known to military users as terrain categorized images, or Tercats) traditionally require a highly trained analyst two to three labor-days to complete. It is desirable to automate as much of the process as possible to reduce Tercat generation time, reduce analyst bias, and increase repeatability of Tercat generation. Mystic was developed to address these issues and to standardize the production, quality, and content of Tercats.

Mystic incorporates the genetic algorithm (GA) at its core to create a non-linear classification approach (Larch, 1994). Genetic algorithms require a two-step process. In the first step, training sites are selected and labeled by the user for each terrain category. One genetic algorithm rule is then generated for each category. In the second step, the rule-set is applied to the same or similar imagery to generate a land cover classification map.

Mystic's training phase requires that rules describing the categories be created. The rules are designed to converge on an optimized set of rules that satisfy two constraints: the best representation of the terrain category, and the best differentiation from all other included terrain classes (background). In the production phase, a rule-set is selected and applied to imagery containing the same or a similar set of terrain classes. Projects are underway to determine the limits of extendibility of the training set for diverse terrains and seasons. The application accepts imagery with any number of spectral bands. The rule generation portion of the program is time-consuming, while the application of the rules on a multispectral image is both automated and fast. Once rules are generated for a given terrain region, those rules can be applied to other images of a similar terrain.

A genetic algorithm rule is an arithmetic/logical equation involving band selections, coefficients, and thresholds. During the training phase, the GA searches for values of each which provide the best classification rate. The initial delivery of Mystic uses a six-band linear equation. This usually proves satisfactory for coarse classifications, but gradually deteriorates as more classes are added to the class map.

Research has begun on more sophisticated equations involving logical combinations of diverse arithmetic forms, and on the expansion of the equations to include spatial measures such as chromatic texture. Mystic has been enhanced to easily add new equations, which will make it a research tool as well as a production capability. Research also is in progress to develop accuracy metrics that will assist users of these products in assessing the quality and relevance of a Tercat to meet their requirements. Mystic has been expanded for use with 1 m 4 band multispectral data.

Interactive Change Detection

The Prototype Image Screening and Change Editing System (Pisces) was developed to detect changes in two Landsat images. The system, originally developed in VMS, was rewritten under UNIX to run in the MATRIX environment. The original algorithm was developed for change detection in temperate forest scenes. In the process of re-implementing Pisces, the algorithm was expanded to operate in arid and tropical regions.

Pisces is an interactive change detection technique that can screen for clouds, vegetation and shadows prior to running one of a selection of change detection algorithms. These algorithms are tailored for temperate regions, arid regions, tropical regions, single bands, and tasseled cap transformations. The user can select from a palette of change features for each of the five algorithms. The temperate region palette includes a 6-band forest change-feature, 3-band forest change-feature, and a single band change-feature. The tropical region palette includes a forest change-feature, tropical change-feature, field change-feature, or general changes. The arid region palette includes asphalt, clay, other man-made features, and general change detection. Under single band change detection, the user can select any of the Thematic Mapper bands (1 through 7). In selecting tasseled cap change detection, the user can select any of the 6 tasseled cap bands: brightness, greenness, wetness, haze, or the fifth or sixth tasseled cap band.

Once the feature space is selected and calculated, the user can screen the image for the presence of clouds, snow, water, shadows, vegetation, shadowed vegetation, or forested areas. Each of these features has between two and four thresholds used to generate the feature mask. Initial thresholds are set by the program, but the user may adjust them interactively by modifying the parameters used in calculating the thresholds. The change image generated by the process contains red and cyan overlays indicating changes between the two dates of imagery. The product does not distinguish between types of changes and must be analyzed by trained personnel.

Automated Change Detection

The goal of the automated change detection program was to develop techniques that would answer spatial queries regarding changes in a geographic region such as "How many acres of this forest has been clear cut?" or "Where are the areas of new construction in this geographic region?"

The challenge with automating change detection is to accurately locate only changes significant to a specific application, screening out irrelevant changes such as those due to clouds, and variations in sensor platform, atmosphere, illumination, and sun angle. For these reasons, automated change detection was one of the primary incentives for developing several of the preprocessing algorithms described above, especially automated co-registration, atmospheric correction, and in-scene radiometric balancing.

Due to the complexity involved in developing a fully automated change detection (CD) system, DLPO sponsored the development of three CD prototypes, specifying that each prototype would be integrated with a Data Base Management System (DBMS). The inclusion of a DBMS is critical to an operational system because it provides the structure for storing, retrieving and analyzing changes over time so that

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temporal trends can be discerned for a given geographic region. The image of change objects can then be ingested in a GIS with change objects attributed by the DBMS. The DBMS also provides the ability to sort changes by any stored attributes such as size of area, date of last change, and type of change.

Three prototypes were developed and evaluated for their potential for operational mission-oriented change analysis (Brennan *et al.*, 1994; Davenport *et al.*, 1994; Bullock *et al.*, 1994). All of the systems used an SQL DBMS integrated with a change detection engine to automatically extract changes. The changes can be sorted by size of change feature, change significance index, and status of the change feature (accepted, rejected, unreviewed). A mission editing subsystem was provided with one of the prototypes that enables the creation of custom change missions from the suite of available missions and algorithms. In this way, new CD missions can be added to the system without additional development effort. Some of the missions delivered with the prototypes were agricultural changes, new construction, new waterfront construction, forest clearcuts, reforestation, and total land cover change.

The CD system currently under development represents a consolidation of two of the delivered prototypes. These prototypes scored highest in complementary portions of the system evaluation, so the final system will have the architecture, DBMS and some of the CD algorithms from one system integrated with the tailorable mission editor and other algorithms from the second system (Davenport and Sailer, 1996). The algorithmic basis for the CD missions developed for the three prototypes draw upon a large body of change detection research. The result is a series of CD missions that use a variety of mathematical transformations based on different physical models. Additional research will be conducted to extend the current suite of algorithms and missions and to test the extensibility of the current algorithms to diverse terrains and conditions.

Automated Extraction of Lines of Communication

The development of a tool for automatically extracting and labeling Lines of Communication (LOC) from digital multispectral imagery is a critical capability for populating geographic data bases that are both current and accurate. LOCs include roads, rivers, railroads, bridges, utility and powerlines. Because of the technical challenge of this project, DLPO awarded contracts to three different contractors to develop separate prototype LOC extraction systems. The prototypes developed (Lersch *et al.*, 1994; Bullock *et al.*, 1994; Gee, 1994) were integrated with a DBMS to maintain temporal tags and facilitate constructing, editing and labeling LOC types.

The accurate extraction and labeling of LOCs with 30 m pixels is difficult and not yet solved with TM imagery. Two of the contractors were awarded follow on contracts to continue research and development and extend their techniques to high resolution multispectral imagery. The technical evaluation of the delivered prototype systems found that one of the systems had a superior architecture and DBMS structure, while the other system contained innovative segment joining and line extractor algorithms. One of the systems also delivered an innovative manual approach as a backup technique for difficult LOCs. The technique enables a user to manually position the cursor on an LOC or more than one LOC and the system will construct the rest of the LOC in all directions around the starting position.

As higher resolution systems become commercially available, the issue will revolve around selecting the optimum scale for accurate extraction of the desired LOC. The highest spatial resolution imagery available may not provide the best input to such a system. The optimum scale for major highways and rivers will be different than for railroads or power lines. The LOC project originally was conceived to take advantage of the 15 m panchromatic data from Landsat 6 merged with the 6 TM reflective bands. The failure of Landsat 6 in October 1994 forced the program to refocus on Landsat 5 capabilities. The surprising success of the prototypes developed using unsharpened 30 m TM imagery demonstrated the feasibility of an automated LOC extraction capability when future higher resolution MSI becomes available. Increased performance is anticipated with the project's current focus on higher spatial resolution imagery such as is planned by EarthWatch, Inc. (Scott, 1995) or Space Imaging, Inc. (Newslink, 1995). The EarthWatch system is planned to contain sensors with 15 m multispectral and 3 m panchromatic imagery. This suggests that given 15 m MSI potentially merged with co-registered 3 m panchromatic imagery, the automated LOC system would be set up to extract larger spatial features at one scale and smaller features at a larger, more optimal scale. It is possible that the 15 m MSI will be a preferred scale for many of the larger LOC features. The final products planned are a series of data planes with attributes that label roads as minor or major, rivers, railroads, fire breaks and other LOCs existing in a geographic region.

Bathymetric Mapping

Generating bathymetric maps worldwide requires enormous ocean-going resources, and the sea-truth gathered is a collage of point measurements. Consequently, most coastal maps are well out-of-date, and all are best-estimate surface interpolations that may not adequately represent the complexity of the ever-shifting seafloor. To address these issues, this project began with the audacious goal of generating bathymetric image-maps without need for onsite sea-truth measurements. Landsat Thematic Mapper does not have the signal-to-noise over water to achieve this goal, but it is hoped that the foundation laid will encourage future satellites to provide the requisite data quality.

In the meantime, research continues to enhance an early prototype application. This application includes the effects of the atmosphere, water-surface reflectance, transmission in water, water-borne biologics, seafloor types, and tides (Brennan and Lewis, 1995). Using Landsat TM imagery, relative bathymetric image-maps can be generated, which can be calibrated with only a score of sea-truth measurements, instead of the hundreds to thousands normally required for such a large region. The second phase of this research will improve the phenomenological modeling, extend the mapping to high resolution multispectral imagery, and intensify the validation and accuracy assessment.

The Production Program

Computing power has become sufficient to allow for high volume production on standard COTS hardware. However, given the enormous capability and flexibility of COTS image processing and GIS software, considerable expertise and training typically is required on the part of analysts to consistently produce a full range of image products that include radiometrically balanced mosaics containing a dozen or more images, land cover classifications, change images and annotated ground control image chips used for developing a structured library of ground control points. In addition, it is desirable to automate redundant processing so that the analyst's time is used effectively for higher level interpretation and analysis. The efforts described in this section —Common Product Generation and Tiered Product Generation—were developed for production environments to minimize the user inputs required to generate image products that are in constant demand. Both of these systems are highly automated, emphasizing streamlined processing, quality control and product standardization and consistency.

Tiered Product Generation (TPG)

This application was developed, within the MATRIX environment, in response to requirements from Air Force Space Command. TPG rapidly generates a series of image products with the same centroid. The products are designed for dissemination to combat air squadrons. The areal coverages are respectively 50x50 mi.; 25x25 mi.; 14x14 mi.; 6x6 mi. and/or any other user defined area. The user selects the centroid of the image products and the products desired. The respective image products are generated with scales, grid lines and locational information. The user also can select a ground control point which improves the accuracy of the product from approximately 250 m to approximately 60 m. Although COTS products were available to create these products, training and production timelines were not acceptable. TPG provides the capability of users with little training to generate these products rapidly.

Common Product Generation: An Image Product Production System

The production system component of the MAGISTIC program is called Common Product Generation (CPG). The system is designed to guide a user through the production of a set of standard image products using digital multispectral Landsat and SPOT imagery. The software is based on a set of image processing scripts developed for the government by a team of image processing experts. The software is designed so that with minimal training and expertise, users at different locations can produce the same suite of image products whose quality and information content conform to the same set of processing and accuracy standards.

The image processing scripts provide the sequence of steps that a user follows in the production of a given image product. The scripts were designed to be implemented in any COTS image processing software package that contained a full complement of pre-processing, geometric and radiometric correction, enhancement, feature extraction and map production software. In addition, the software needs to contain a macro language to minimize the independent software development required to produce the full suite of image products.

The CPG software module was developed using the ERDAS Imagine software package. The full Imagine package underlying CPG is accessible to the more experienced user, but the software guides a user through a structured processing flow. As the user moves forward through the processing chain, the icons are highlighted. Although the user cannot skip forward before a step has been completed, the user can move backward in the processing chain to modify or correct prior processing or information for the image template.

Several design goals have been implemented in the current version of CPG. The system minimizes user input requirements by reading information from the Landsat or SPOT headers whenever possible and by creating a list of preset user preferences that can be tailored to fit any user site. There are a wide range of preferences available that include production site location, default processing options, and access caveats that are produced on the final hardcopy or softcopy product templates. The software processing options are structured to provide defaults relevant to the respective processing scenario. The streamlined structure of the production software also allows for more efficient processing for the image product suite.

The following describes the suite of products that have been incorporated into the CPG production system:

Analysis Image is an overview image of a Landsat scene. This product uses only information supplied with the image header to reference its spatial coordinates. The product is designed to be enhanced using contrast stretches and spatial filters. There is a Land/Water mask capability so that both areas can be separately enhanced. This is especially important for areas of high contrast near large water bodies. Land/Water separation is provided for most of the CPG products. Figure 1 is an example of an Analysis Image product.

Image Graphic is an Analysis Image that has been geometrically corrected. Registration is done using ground control points, map coordinates, and an optional digital elevation model.

Tercat Image Graphic is a georeferenced image in which the picture elements have been labeled into groups corresponding to land cover types, and each land cover type has been assigned a unique color. The user can elect a directed approach or use the underlying ERDAS classification software. The directed approach guides the user through a combined supervised and unsupervised classification approach. The training site selection portion establishes a predefined table of default land cover classes that can be customized for production sites. This enables production sites to standardize the labeled categories on its products.

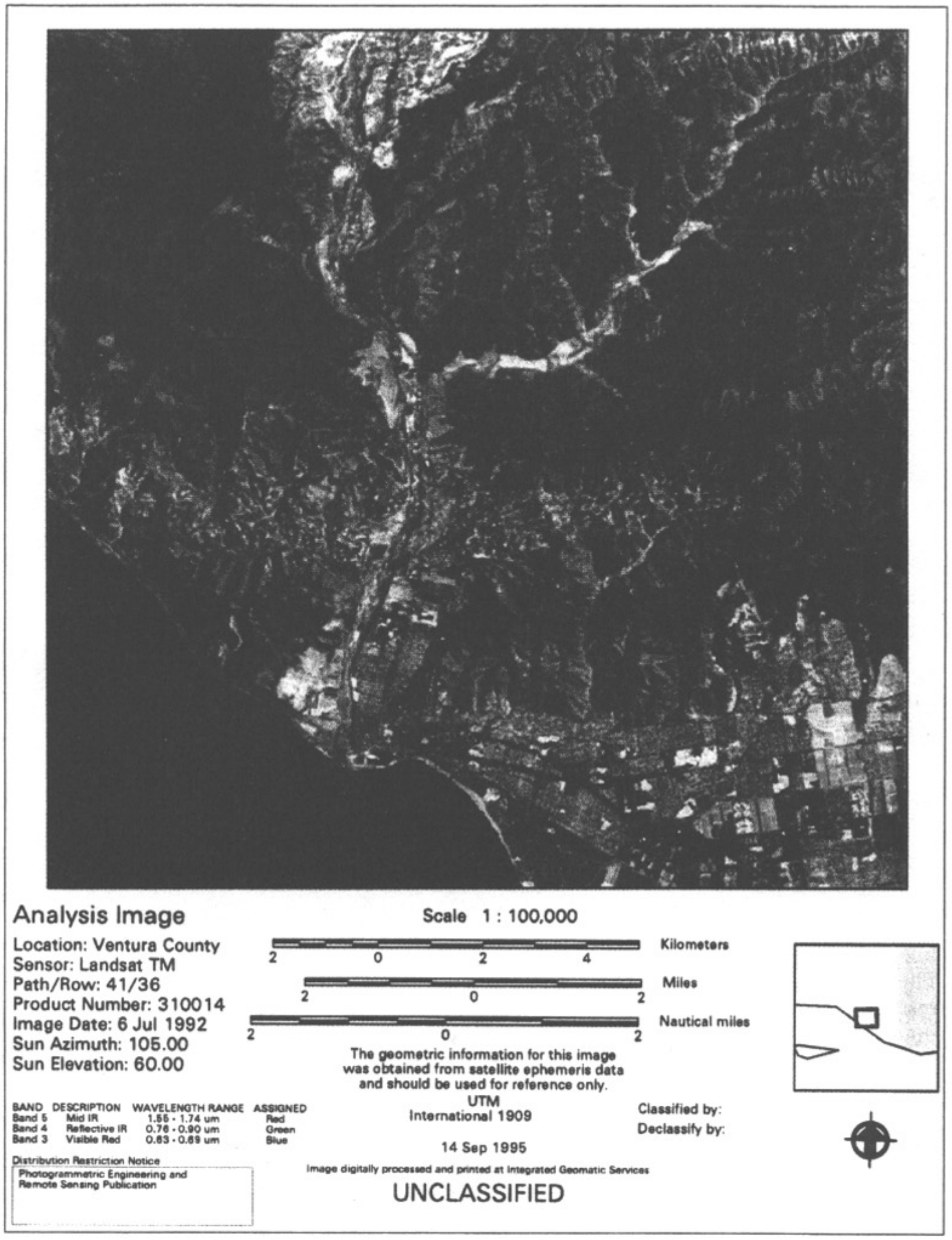

Figure 1. Example Analysis Image Product created using CPG. The product is a 1:100,000 scale subscene of a Landsat Thematic Mapper Image of Ventura County, California using a Short Wave Infrared band combination (5,4,3). The image was enhanced using a standard equal area stretch to each of the three bands. The marginalia displayed in the product is part of the product format and automatically generated from image header data.

Mosaic Image is a georeferenced image composed of multiple adjacent Landsat images that have been georeferenced. The products may be created separately in previous software sessions or as part of the mosaic process. The overlap areas are blended and radiometrically balanced.

Tercat Image Mosaic is a georeferenced image composed of multiple Tercat Image Graphic products. The products may be created separately in previous software sessions or as part of the mosaic process. Conflicts in terrain category in the overlap areas are resolved by a series of pre-established rules.

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Ground Control Chip is a three band subimage containing a ground control point at its center. The latitude and longitude of the control point is labeled on the product. Typically, the ground control point is selected using available larger scale maps or images that are georeferenced. The product also includes a description of the feature used as a ground control point. The products may be used to form the basis of a library of control points suitable for image registration.

Perspective View is a three band three-dimensional view of SPOT or Landsat data. A digital terrain model such as the Defense Mapping Agency's Digital Terrain Elevation Data or the U.S. Geological Survey's Digital Elevation Model is required to generate this product. The user drapes the image data over the digital elevation model and manipulates icons to vary the target and viewer perspective.

Change Image/Reference Image is a color-coded change image formed from two sets of Landsat or SPOT images from two separate dates. The application used is the Interactive Change Detection described previously. The change image is color-coded to depict increases in change feature value in cyan and decreases in red. Areas that are unchanged are displayed in the gray tones of TM band 4. The software provides the user with the capability of excluding clouds or vegetation by creating masks of these areas and excluding them from the change detection algorithms

Image Map is a SPOT panchromatic image that has been rectified using a USGS DEM or Defense Mapping Agency Digital Terrain Elevation Data. The output product is a 1:24,000 scale image that covers an area 7.5 minutes on a side.

Accuracy Assessment

Image processing as a field is moving from the generation of image products that require interpretation by a trained analyst to information products that answer questions of a spatial nature. The thematic products described here are critical pieces in the generation of several information products. There are many information products in common use throughout the remote sensing and GIS communities, many of which are assimilated manually through the use of a series of hand drawn graphics or images or through a combination of hardcopy and digital products. Many other information products are developed by image processing and GIS specialists on a custom basis. Because all of these products involve overlaying at least one spatial product upon another, the accuracy of the composite product (an information product) is often poorly known.

The basic problem is that all maps and image products have an inherent imprecision and even the most accurate thematic product will contain some error which may be randomly distributed or spatially clustered. As users move to information products, accuracy metrics must be developed for each image or thematic product and a composite accuracy score and spatial error distribution distributed with the information product. The image interpretation program currently is conducting research into the development of accuracy metrics for the Tercat and Change Detection projects (Brennan, 1994).

An Uncertain Future

With several promising commercial high resolution MSI satellites in development, the focus of research shifted in January 1996 from 10-30 m resolution imagery to 1-5 m resolution imagery. Since a short-wave infrared (SWIR) band may not be available on most sensors, but will become available in the future, algorithms have been designed to accommodate both SWIR and VNIR data sets. The applications being adapted to high resolution imagery include Mystic land cover classification, automated change detection, lines of communication extraction, and in-scene radiometric balancing.

The Office of the Secretary of the Air Force terminated support for the program in October 1996. Of the 12 applications described in this paper, four have been deployed to operational government users (Pisces, CPG, TPG, Panchromatic Sharpening), four are ready to be deployed (Atmospheric Correction, Co-registration, Radiometric Balancing, and Thermal Sharpening), two are in advanced stages of development with robust prototypes in beta testing (Mystic land cover classification and Automated Change Detection), one is in an advanced stage of research with a prototype in alpha testing (Lines of Communication Extraction) and one has a robust application with algorithms in development (Bathymetric Mapping).

The government has created a new organization, the National Imagery and Mapping Agency (NIMA), which is a conglomeration of many existing organizations. It is uncertain which, if any, organization will

As users move to information products, accuracy metrics must be developed for each image or thematic product and a composite accuracy score and spatial error distribution distributed with the information product.

continue the work described in this paper and carry it to completion, but NIMA is a candidate. Unfortunately, there seems to be little motion in this direction. The government has encouraged the algorithm developers to commercialize these software applications. Anyone interested in more information about any of the applications described in this paper should contact the Principal Investigator to which each section refers.

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