Reprinted from

Ninth International Symposium

Machine Processing of

Remotely Sensed Data

with special emphasis on

Natural Resources Evaluation

June 21-23, 1983

Proceedings

Purdue University
The Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907 USA

DEVELOPMENT OF THE JSC THEMATIC MAPPER QUICK-LOOK PREPROCESSING CAPABILITY

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I. ABSTRACT

With the launch of Landsat-4 in July, 1982, the remote sensing community has been provided a new earth orbiting multi-spectral sensor which has increased spatial and spectral resolution over previous Landsat instruments. This new instrument, the Thematic Mapper, is a forward step in the progression of remote sensing technology, incorporating the knowledge and experience gleaned from early scanning instrument endeavors as well as utilizing the latest available satellite stability and pointing capability.

Landsat ground processing elements must accomodate a seven-fold increase in data per scene from Thematic Mapper as compared to previous Multi-Spectral scanner data. Many of the existing scanning image processors had been developed during the early 1970's and were not capable of handling large volumes of data. The problem consequently became a manifestation of the adaptation of existing systems, wherever feasible, and in many instances, the implementation of new processors designed for increased data volume handling.

This paper presents the development of the Thematic Mapper ground Preprocessing capability of the Earth Observations Data Laboratory (EODL) at the Johnson Space Center. The implementation of new processing elements and the utilization of existing systems in the EODL to handle Thematic Mapper data are reviewed in detail.

The EODL Thematic Mapper Preprocessor has been designed to provide researchers with satellite imagery data over selected areas of interest in data sets which are sized to be computationally manageable.

II. BACKGROUND

In early 1982, the design of a system to preprocess TM imagery data from Landsat-4 was in the formulation stages at JSC. The preprocessing requirements were straightforward: to read TM imagery from computer tapes; to extract from image scenes, areas of interest suitable for scientific analysis; and to register TM imagery to other imagery from the same area. The production of film products from TM imagery was also a consideration in the design. It was realized at the time that the Jet Propulsion Laboratory's (JPL) VICAR image processing program, which was installed and operational on the EODL computer was capable of performing most of the TM preprocessing task elements. Unfortunately, the VICAR program operates under a non-native system control program on the EODL computer, making input/output and operations with peripherals very cumbersome. So the idea of utilizing VICAR for the whole of the TM preprocessing task was discarded. However, the design of the JSC TM Preprocessor was greatly influenced by VICAR concepts, including the utilization of many of the computationally efficient VICAR image and array manipulation subroutines. The VICAR subroutines are FORTRAN callable

Assembly Language sub-programs designed to perform particular tasks. The functions provided by these routines are many and varied. A programmer has available a host of powerful tools with which to perform tasks that are either difficult under FORTRAN or not computationally efficient. The use of these VICAR primatives allows rapid development of sophisticated image manipulation programs. It is far simpler to make one appropriate VICAR subroutine call rather than to spend time programming the logic required to process all the elements of a line of imagery. Thus the concentration of the design can be more focused toward the overall tasks to be performed, affording the opportunity to satisfy the design requirements better and more efficiently. The JSC TM Preprocessor makes extensive use of the VICAR subroutine library which provides an environment that supports rapid software development.

One of the considerations driving the JSC TM Preprocessor design was the completeness of the GSFC SCROUNGE (LASLIB) TM data products. LASLIB TM tapes are radiometrically and (partially) geometrically corrected computer compatible tapes, not requiring the "A" to "P" corrections similar to Landsat-3 Multi-Spectral Scanner (MSS) imagery. Since the TM imagery was already on computer compatible tapes, there was no requirement to implement an instumentaton (high density) tape to CCT capability in support of TM preprocessing. Finally, the band-to-band registration for LASLIB TM imagery is better than $\pm$ 0.2 pixel, so there was no requirement for a TM channel-to-channel registration capability either.

III. APPROACH AND DESIGN

The JSC TM Preprocessor was designed to meet the requirements of providing imagery to researchers in a form suitable for their use. Computationally manageable data sets containing imagery over areas of scientific interest had to be extracted from 185 kilometer square full scenes ($\sim 2.4 \times 10^9$ bits/ scene) of TM imagery. A VICAR program named "SAR" (for Segment Area Rectification) served as a guide for creating the JSC TM Preprocessor read and extract program. The new version of SAR was written to perform the sub-image extraction commencing at user specified line and sample of the full image and to output the requested number of lines and samples. In order to locate the areas of interest from within the full image scenes, it was necessary to create a routine to relate the line and sample numbers of a given image to geodetic latitude and longitude coordinates. From the known longitude/latitude and line/sample of the TM scene center, spherical trigonometric relations are developed to compute the latitude/longitude of each pixel within the image. Because the JSC requested TM scenes all lie between the 45 degree North and South parallels, the map projection of the TM imagery is sufficiently close to earth geodetics to allow the use of spherical trigonometry rather than projective geometry for the coordinate conversion process. Incidentally, the coordinate conversion step is a result of JSC researchers having traditionally specified image areas-of-interest in terms of geodetic coordinates, so it was imperative to have a means of relating image coordinates to latitude/longitude. Once an extraction starting line and sample within the image have been determined, the values are input into the EODL extraction program. The program, termed "SARLAS" (SAR from LASLIB TM tape), utilizes the NASA GSFC high-speed input/output (I/O) package to read the LASLIB TM image tapes. The high speed I/O package executes fifty times as fast as the conventional FORTRAN I/O package, thus considerably reducing the time required to perform a read and extraction from a full frame TM image tape set. It should also be noted that SARLAS has programmed into its structure the layout of the LASLIB TM tapes, so the read and extraction process does not require much user direction.

It was the initial JSC plan to use a VICAR program for registration of TM to other imagery (and vice-versa). However, the VICAR interface is so unwieldy that it was decided to create a substitute program to perform the registration job. The resulting program is designed to perform a least-squares global (meaning over the extracted image) correlation surface fit from registrant to reference tiepoints. The resulting correlation surface provides corrections for image to image differences in offset, scale, skew and rotation as well as image keystoning effects. The program also will perform the rubber-sheeting operation to create the output imagery predicated on the computed correlation surface. Because the EODL tiepoint registration processor (TIEREG) operates in the image coordinate domain (line/sample as opposed to latitude/longitude), any digital imagery can easily be accomodated by the program. The acquistion of the JSC Image Analysis Station (IAS) has greatly simplified the process of determining registrant to reference imagery tiepoints, but tiepoints can and have been acquired by other means (line printer output). The output from the TIEREG program is a registered (to some reference) imagery data set, which has been fully extracted and resampled to the reference image grid. It is noted that there is for the EODL TM Preprocessor TIEREG registration routine an alternative to the global surface fit described above. The alternative registration routine essentially forms triangles of the tiepoints and performs adjacent triangle mosaicking. An affine transformation is provided for data within each individual triangle to correct for image to image offset, scale differences, skew and rotation but edges formed by the triangle sides are maintained intact. The processor is valuable for registering two images in vastly different geometric coordinate systems.

Other programs have been written supplementing the main-line JSC TM Preprocessing capability. A generalized image resampling capability has been included to interpolate image pixels to alternate output grids. The program has been most useful for creating rectangular pixels from square ones, square pixels from rectangular ones, small pixels from large ones and large pixels from small ones. Many of the classification and clustering programs on the EODL computer originally were created to process imagery of certain exclusive dimensions. Because of long experience with these in-place processors, JSC researchers were quite interested in the performance and responses of the processors with TM imagery. It should be noted that for the resampling program the method of interpolation is specifiable (nearest neighbor, bilinear or cubic convolution) as well as the output image grid size. Another general-purpose image processing capability written in support of the JSC TM Preprocessor is a box (convolutional) filter program. The weights of the filter are interactively specifiable and with the proper choice of these weights, the program will provide high and low pass filtering, edge detection, image gradients, Laplacian edge enhancement, noise removal and image scaling. Finally, a general purpose image rotation program has been created ancillary to the JSC TM Preprocessor. The function of the program is to perform the rotation of an image through any specifiable angle and to output the rotated image. The program is useful in providing an initial alignment of images from two different sensors. It is true that the tiepoint registration program written in support of the TM Preprocessing function will remove any image-to-image rotation, assuming that proper tiepoints are provided. However, in practice it is often difficult to determine good tiepoints for images that show a great deal of initial rotation from one another. As a final note regarding the supplementary preprocessing programs, all of the programs are available to the JSC researchers as user-friendly interactive tools on the EODL computer to provide additional TM preprocessing which might be required.

The production of film products of TM imagery has been a prime concern in the design of the JSC TM Preprocessor. The III Systems' FR-80 Precision Film Recorder, like most digital devices, has a particular format for image data input and the reformatting of TM data into the FR-80 compatible format is one of the tasks of the JSC TM Preprocessor. The FR-80 film recorder is capable of providing basically two products. The first product is a descendant of the LACIE project of the mid-1970's and has fairly rigid constraints. Color balance, pixel sizes and shapes are preset and not easily alterable. However, the color repeatability for multiple acquisitions is quite high, therefore there remains a great deal of interest in providing the LACIE film capability. The second FR-80 program (the PIXEL Plotter) is quite flexible in providing film products to researchers. Image size (up to 4000 pixels by 4000 lines) is specifiable as is pixel shape.

The majority of the processes for color balancing, film gamma correction (if desired) and image intensity modifications are performed by the EODL host computer and not by the FR-80 PIXEL Plotter program. Nevertheless, researchers are provided a great deal of latitude in the specification of the output film products from the PIXEL Plotter program. The JSC TM Preprocessor generates computer compatible tapes for each of the FR-80 processors as well as performing the intensity and color balancing functions required of the PIXEL Plotter program.

IV. SYSTEM PERFORMANCE

Timing analyses of the execution of the JSC TM Preprocessor task functions are referenced to performance with actual LASLIB TM imagery. It should be noted that the timing results detailed herein relate to the central processing unit (CPU) time for a National Advanced Systems AS/3000 mainframe, utilizing an International Business Machines' VM/SP system control program.

The JSC TM Preprocessor requires twelve seconds of CPU time per TM image channel to read and extract an area of interest from a full TM scene. The time requirement is relatively independent of the size of the extracted area. The majority of the time is spent in reading the full scene and not in performing the extraction. Execution of the generalized image resampling routine which outputs an image to an alternate grid requires twenty-four seconds of CPU time per channel, assuming a 512 pixel by 512 line input image. The resampling method employed to obtain this timing figure is bilinear interpolation. Nearest neighbor interpolation requires less time while cubic convolution requires more. The generalized image rotation routine execution time is dependent upon the size of the input imagery as well as the rotation angle. If the image is rotated through a cardinal angle (90, 180 or 270 degrees), less CPU time is required than for other angle rotations. This is because cardinal angle rotations employ nearest neighbor resampling while other angle rotations are performed using bilinear interpolation. The tiepoint registration program execution time is also directly proportional to the size of the imagery being processed. The AS/3000 CPU time required to tiepoint register a 512 pixel by 512 line image is forty-eight seconds per channel. This result is predicated on the use of bilinear interpolation resampling. Again, nearest neighbor interpolation requires less time and cubic convolution more. All other task functions of the JSC TM Preprocessor (for example, the FR-80 tape creation job) require less than two seconds of CPU time in order to execute. The majority of the time spent preprocessing TM data is in the tiepoint registration process.

The execution requirements of all the JSC TM Preprocessor functions which make use of image resampling/interpolation can certainly be enhanced by rewriting the routines in assembly language. All of these interpolation subroutines initially were written in FORTRAN. The bilinear interpolation routine was later rewritten (but still in FORTRAN) to exclude all floating-point operations in the computations. The integer arithmetic version of the routine resulted in the resampling operation using about 30% less time to execute than the comparable floating-point requirement. An assembly language bilinear resampling routine, using floating arithmetic, was written and was found to execute slightly faster than the integer arithmetic FORTRAN version. Ultimately, an integer arithmetic, assembly language implementation of the interpolation routines should yield the fastest throughput.

V. SYSTEM TRANSPORTABILITY

The JSC TM Preprocessor is written entirely in FORTRAN and IBM assembly language source code. The total amount of source code comprising the program, excepting the GSFC high speed I/O package is approximately 2000 lines. The high speed I/O package consists of 1600 assembly language source lines.

In order to minimize the computer core requirements of the JSC TM Preprocessor, most routines are designed to operate with only one line of imagery at a time. The bilinear interpolation routine requires that two image lines be in core at once and cubic convolution requires four. Only the tiepoint registration and the image rotation programs require that the entire image be loaded in core all at once. Perhaps the use of overlapping image segments in these routines could reduce the current core requirements.

The JSC TM Preprocessor can easily be installed on any large computer using an IBM system control program. The implementation of the preprocessor at JSC initially was under VM/370 CMS but recently the operating system was replaced with VM/SP CMS. Few anomalies were encountered with the preprocessor following the change to the new system. No problems are anticipated for installing the preprocessor under OSVS/1, MVS or EOS, all of which are IBM system control programs. The installation of the preprocessor on any other system could be time consuming simply because of the fact that a great deal of IBM assembly language has been utilized in programming the VICAR subroutine library. Also it should be noted that extensive use of byte (8-bit) arigthmetic has been made in the preprocessor and not all computers support such operations.

VI. CONCLUSION

The JSC TM Preprocessor was designed in a fairly short time to perform specific tasks with LASLIB TM imagery. The tasks were well defined -- to read the TM image tapes, to extract areas of interest from the imagery and to register the extracted imagery to suitable references. The format of the LASLIB TM tape product was late in development so the front-end of the preprocessor had to be made fairly flexible in anticipation of changes. However, once the tape format was defined, the structure of the format was incorporated into the preprocessor in order to minimize operator interaction. Ancillary programs for image enhancement, rotation, filtering and modification of pixel size have provided researchers with optional preprocessing capability, should the techniques be required. Finally, all of the preprocessing programs have been designed as interactive, user friendly tools to provide researchers with a latitude of choices for TM imagery and products.

REFERENCES

1. Seidman, J. B. and Smith, A. Y., "VICAR Image Processing System, Guide to System Use", National Aeronautics and Space Administration, Jet Propulsion Laboratory, December 1979.

2. "Landsat-D Assessment System Library Computer Compatible Tape", Tape Format Document, WBS No. 10T031, National Aeronautics and Space Administration, Goddard Space Flight Center, June 1982.

3. Juday, R. D., "Colorimetric Considerations of Transparencies for a Typical LACIE Scene", Proceedings of Technical Sessions, The LACIE Symposium, National Aeronautics and Space Administration, Johnson Space Center, Vol. II, October 1978, pp. 887-897.

4. "Landsat-D Mission Operations Review", National Aeronautics and Space Administration, Goddard Space Flight Center, April 1982.

5. Moik, J. G., Digital Processing of Remotely Sensed Images, (NASA SP-431), National Aeronautics and Space Administration, Scientific and Technical Information Branch, Washington, D. C., 1980

BIOGRAPHICAL BACKGROUND

Jimmy R. Gilbert

Jimmy R. Gilbert received a Bachelor of Arts degree from Oklahoma City University in 1965. Since June, 1966, he has been employed by the National Aeronautics and Space Administration at the Johnson Space Center in Houston, Texas. From 1966 until October, 1979, he was assigned to the Ground Data Systems Division / Flight Support Division as a mathematician/ engineer on Apollo through the Shuttle Approach and Landing Test missions. His assignments were primarily computer analyses and modeling of the flight systems, specifically in the area of spacecraft guidance, control and navigation. In October, 1979, he was reassigned to the earth resources program at JSC where he has been active in image-to-image registration development, programming and research.