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RESULTS OF PRECISION PROCESSING (SCENE CORRECTION) OF ERTS-1 IMAGES USING DIGITAL IMAGE PROCESSING TECHNIQUES

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ABSTRACT

ERTS-1 MSS and RBV data recorded on Computer Compatible Tapes have been analyzed and processed, and preliminary results have been obtained. No degradation of intensity (radiance) information occurred in implementing the geometric correction. The quality and resolution of the digitally processed images are very good, due primarily to the fact that the number of film generations and conversions is reduced to a minimum. Processing times of digitally processed images are about equivalent to the NDPF electro-optical processor.

I INTRODUCTION

Investigation Objectives. This investigation deals with applying digital techniques to the processing of ERTS-1 image data, and in particular, to the Precision Processing (Scene Correction) of ERTS-1 data. The objective of the investigation is to geometrically correct an ERTS image to a UTM projection, maintain or correct the sensor radiometry (intensity), fully annotate the data, record the results on computer compatible tape (CCT) and on film, and evaluate the results.

Investigation Approach. Based upon previous analysis and experimentation (References 1 and 2), it has been felt that both good radiometry and geometry can be achieved by digital image processing, which minimizes the number of film generations and data conversions. Figure 1 shows a digital approach used to achieve Scene Correction of ERTS images. The sensor data, on computer compatible tapes (CCT's) are read into a digital computer. The geometric and radiometric corrections are implemented through software, and standard annotation data is combined with the processed image data to generate another CCT containing a scene corrected image. This tape data is then read into a film recorder, which records the data directly on 240mm (9.5 in.) film. The advantage of this approach is that the final product is a second generation photo and involves no unnecessary data conversion stages.

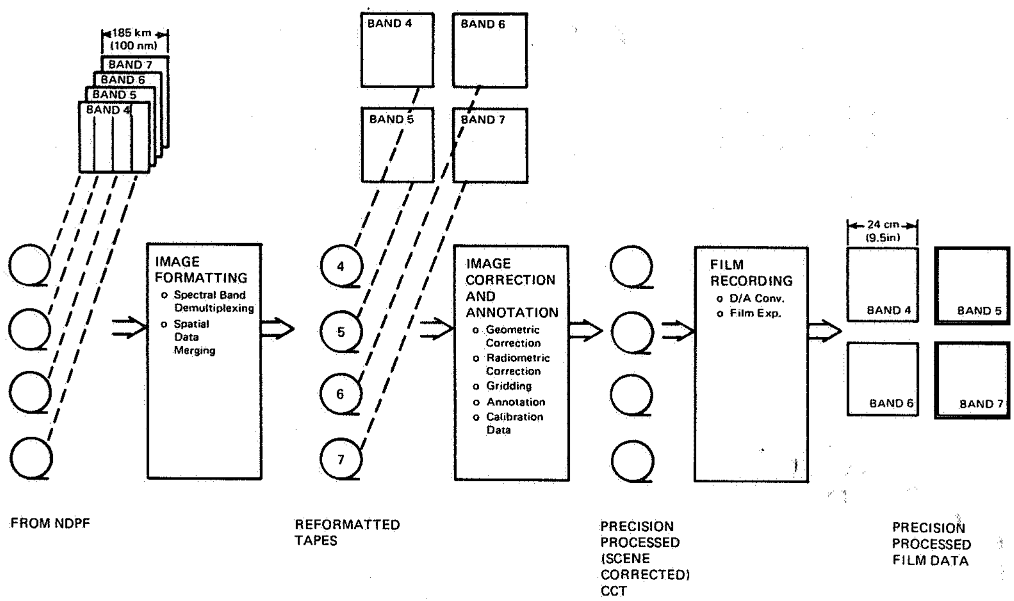

Figure 1. Digital Image Processing Approach Scene Correction

II EXPERIMENTAL APPROACH

Sensor Errors. The principal errors associated with the data received from the two ERTS sensors are listed in Table 1. These errors are fully described in Reference 3. If these errors are to be corrected, they must be either predictable or measurable. Errors due to MSS mirror velocity, panoramic distortion, scan skew, and perspective projection are constant (for all practical purposes) and can be predicted in advance. Errors due to spacecraft velocity and earth rotation can be predicted from tracking data. Attitude and altitude errors must be measured for each image. The measurement technique used here involves apparent displacement of ground control points (GCP's)—recognizable geographic features whose actual positions are well known. The image locations of the GCP's are determined by application of the Sequential Similarity Detection Algorithm (described in References 2 and 4) to appropriate areas of sensor data.

RBV scanning raster distortions are measured by observing apparent displacements of a 9 x 9 array of reseau marks etched on the faceplate of each tube. A technique has been developed to digitally locate these marks using a modified form of "shadow-casting (Reference 2). Once the reseau marks are located, the nominal and observed locations are used to evaluate the coefficients of a pair of polynomials which provide a model of the composite effect of the various scanning raster distortions.

Table 1. ERTS Sensor Data Errors

MSS	Mirror Velocity	RBV	Scanning Raster Distortions
	Panoramic Distortion		Perspective Projection
	Scan Skew		Attitude
	Earth Rotation		Altitude
	S/C Velocity		Shading
	Perspective Projection		
	Attitude		
	Altitude		
	Detector Response		

Geometric Correction. The input image is an array of digital data which represents a geometrically distorted perspective projection of some portion of the earth's surface. The output image is a geometrically correct UTM projection of the same ground area. GCP's are located in the input image, and the observed locations are corrected for all those errors which can be predicted or determined from tracking data. The nominal and observed GCP locations are then used to evaluate the coefficients of the attitude and altitude models. All of the error models are combined in a pair of bivariate polynomials which provide a composite, global mapping from output image to input image. Correct locations for only a few output image points are determined from the mapping polynomials. All other points are located by bilinear interpolation over the mapped points.

Radiometric Correction. There are a total of twenty-four detectors on the MSS, each one of which can generate only a small number (64 or 128) of distinct output values. Thus it is quite feasible to define for each detector a table which specifies the desired value corresponding to each of the possible detector output values. Radiometric correction can then be accomplished by a simple table look-up operation. Such correction tables can be used to accomplish a variety of objectives. For example, by computing average values of detector outputs in areas of approximately uniform radiance, it is possible to compute gain and bias corrections which will eliminate striping due to differing detector responses. It is also possible to generate tables which will modify the video intensities to emphasize or enhance specific types of features or to match the data values to the characteristics of the recorder and film used.

III TECHNICAL RESULTS TO DATE

Reseau Detection/Migration. The reseau detection technique was applied to all bands of images E-1002-18134 and E-1014-17375 (which have the greatest temporal separation of RBV scenes received by IBM). Search areas 50 samples square were centered on the expected locations of the 486 reseau. In all cases, as verified by examination of computer-generated shade prints, the detection technique correctly located the reseau marks. The test was then repeated on 486 image areas picked to contain no reseau. In no case was a false reseau selected.

Band 3 was selected to examine for apparent reseau migration over the twelve-day interval spanned by the two test scenes. In only one case was a migration as large as three pixels in either axis observed. This would seem to imply that RBV internal distortions are quite stationary and that the use of small reseau search areas is justified.

GCP Experimentation. The Sequential Similarity Detection Algorithm (SSDA) has been applied to a variety of targets in several image pairs. The results obtained are summarized in Table 2. Although these results must be considered preliminary, certain trends are emerging:

- Performance (i.e., ability to find the feature and average search time) varies from band to band for different types of GCP's. This suggests that in an operational system, the search for a given GCP should be conducted in that band which has exhibited the best performance on that type of target.

- Strong targets (i.e., those which present a large, distinct pattern) are located quickly. Indistinct targets require much more search time. This is what would be expected from the characteristics of the SSDA.

- When a proper combination of target and band is used, search times are acceptably small. (It should be noted that the search times given in Table 2 show the performance of an experimental FORTRAN program. An operational assembly language program can be expected to be significantly more efficient. Further, no sophistication such as hill-climbing has been added to the basic algorithm.)

Table 2. Initial SSDA Results — MSS Data

Target Type	BAND 4		BAND 5		BAND 6		BAND 7		Temporal Separation/ Location/
	No. Found/ Tried	Time (Sec)	No. Found/ Tried	Time (Sec)	No. Found/ Tried	Time (Sec)	No. Found/ Tried	Time (Sec)	
1	5/5	46	5/5	29	5/5	4	5/5	15	17 Days
2	1/1	51	1/1	47	1/1	40	1/1	45	Chesapeake
3	2/2	12	2/2	4	2/2	8	2/2	22	Search: E · 1062–15190
									Window: E–1079–15140
1	4/8	50	7/21	27	15/21	5	17/21	14	18 Days
3	0/0	–	1/2	9	2/2	11	2/2	27	Chesapeake
4	1/1	50	1/1	29	1/1	7	1/1	29	Search: E–1080–15192
5	0/0	–	16/16	9	15/16	27	14/16	50	Window: E–1062–15190
1	4/6	4	6/6	3	5/6	2	5/6	7	
2	2/8	5	6/8	12	6/8	37	6/8	20	36 Days
3	0/2	–	0/2	–	1/2	48	1/2	7	Phoenix
4	2/3	12	3/3	12	3/3	49	3/3	6	Search: E–1049–17324
6	1/2	5	2/2	6	1/2	5	2/2	52	Window: E–1085–17330
7	1/1	4	1/1	3	0/1	–	0/1	–	
1	1/2	5	2/2	3	2/2	3	2/2	6	72 Days
									Phoenix
									Search: E–1049–17324
									Window: E–1121–17330

TARGET TYPE:
1 – LARGE LAND–WATER INTERFACES
2 – NON–INTERSTATE HIGHWAYS
3 – AIRPORTS
4 – SMALL LAND–WATER INTERFACES
5 – INTERSTATE–GRADE HIGHWAYS
6 – HILLS
7 – FIELDS

Note: Times are for 360/65 FORTRAN Program.

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Mapping Functions and Accuracies. APL programs have been used to estimate the accuracy of several different approaches to MSS geometric correction. The first approach used the BIAT attitude and altitude data. The second approach used GCP's to evaluate cubic attitude models but took altitude data from the BIAT. The third approach added a linear altitude model which was evaluated using ground control. The fourth approach fit two 6-term polynomials to the various error models. Results for the four approaches are summarized in Table 3. They show that the use of the BIAT attitude and altitude data is inadequate for precise mapping, GCP's provide significant improvement, and the addition of an altitude model (which increases the GCP requirements by one point) further improves the mapping accuracy. The polynomial fit produces RMS errors that are comparable to the attitude/altitude model combination but maximum errors that are significantly smaller. These results show that, for the images processed, geometric distortions in MSS images are not higher than third degree.

Table 3. Predicted Geometric Correction Accuracies

Scene		Mapping Errors In Meters: BIAT For Attitude And Altitude	GCP's For Attitude Only	GCP's For Attitude And Altitude	6-Term Polynomial Fit
MONTEREY	MAX:	1517	295	115	86
E-1002-18134	RMS:	999	129	66	52
MSS 25 July 1972					
CHESAPEAKE	MAX:	1503	269	202	141
E-1062-15190	RMS:	722	111	61	68
MSS 23 Sept 1972					

Intensity Modification and Striping Removal. Several relatively simple intensity modification experiments were performed on MSS images in order to evaluate the resultant image product in terms of information content and subject quality. Cultural features, such as roads, could be more clearly seen with such an intensity change, and water pollution/sedimentation patterns were enhanced. An experiment to eliminate undesirable striping in the images was conducted, and virtually all striping was removed.

Samples of Precision Processed Images. All bands of the Chesapeake and Monterey scenes were Scene Corrected and recorded on film. Contact prints of two bands are provided at the end of this paper. It is noted that good radiometry and resolution are exhibited.

Processing Times. Table 4 shows the current estimated processing times. No attempt has yet been made to minimize processing times, and these times, although reasonable, are expected to be reduced further through the use of better image management, lower processing overhead, and higher I/O speeds. It is significant, however, that the MSS images are each processed in an average CPU time of less than 3 minutes, and an elapsed time of less than 8 minutes.

Table 4. Current Processing Times

RBV Processing

Reseau Detection — 10 seconds for 81 reseau

MSS Processing (All 4 Bands)

	CPU (Min)	Clock (Min)
Reformatting	1.7	10
GCP Detection (4 Sec/GCP)	0.8	
Geometric and Radiometric Correction	9.0	20
	11.5	30

Notes:

Computer Used — 360/65
Clock Times — Dedicated Computer (Estimated)
Geometric and Radiometric correction (CPU) — First band 3.0 minutes actual, 9.0 minutes estimated for correcting all four bands.

IV TECHNICAL PROBLEMS

Software Errors. When the Chesapeake image was geometrically corrected, some irregularities were found which were not present in the Monterey image. Vertical breaks of two pixels occurred in several Chesapeake images. To aid in finding and correcting any errors in the point shift program, an image consisting of a grid of vertical and horizontal lines was created. The grid image was geometrically corrected by the same program that corrected the Chesapeake images. The irregularities were clearly visible on this image. In addition to the two pixel vertical breaks mentioned above, some two pixel horizontal breaks were found in the horizontal lines of the grid. There were also some two pixel vertical breaks followed by one pixel vertical breaks in the opposite direction. These software problems are currently being addressed.

MSS Striping. Incomplete gain and offset compensation of MSS detector data results in a striping or banding effect when the data is recorded on film or viewed on a computer shade print. This striping is particularly noticeable in near uniform radiance regions and detracts from the image quality. Further, the banding effect has propagated in multispectral analysis programs, causing line by line misclassification errors. Some degree of success has been achieved eliminating striping by individual detector gain compensation.

V ADDITIONAL INVESTIGATION REQUIRED

Based upon the results to date, the following areas require additional investigation and analysis:

Ground Control Point Experimentation. An encouraging degree of success has been achieved in digitally detecting GCP's with temporal separation. However, more analysis is required to assess:

Seasonal Effects — How long a GCP can be used reliably.

Feature Characteristic — What type and spatial characteristics of a feature make it "best", and what are the optimum sizes of the search and window areas.

Spectral Band — What band is best for what class of GCP and least sensitive to uncontrolled variables.

Parametric Selection — What are the best values for the threshold sequence, etc.

Attitude/Altitude Effects — What is the sensitivity of the SSDA algorithm to effects which change the relative geometry of the search and window areas.

RBV Image Processing. Due to the shut-down of the RBV shortly after ERTS launch, processing priority was given to the MSS data. The only processing performed on the RBV data was reseau detection. The geometric correction of the RBV image is expected to be relatively simple. The radiometric correction of the RBV, due to the severe shading effects is expected to be challenging and will require some experimentation.

MSS Image Processing. Two different methods of determining geometric correction functions have been investigated: evaluating coefficients of various specific error models and directly fitting a polynomial function to observe GCP displacements. Polynomial fitting appears to produce more accurate results. It gives a direct compensation for the distortions present and is not subject to misconceptions about the forms of various error models. It appears to require no more ground control information than alternate methods. On the other hand, polynomial fitting can be expected to be relatively sensitive to the locations of the GCP's used. If the GCP's do not sufficiently span the image, the polynomials will be inaccurate in the regions not spanned. The error model approach, because it forces a structure on the correction functions should not be so sensitive to GCP locations. Both methods should be investigated further, particularly with regard to sensitivity to GCP number and location. It may prove that polynomial fitting with a fall-back to error modeling when the available GCP's don't span the image sufficiently is the best approach to use.

VI PRELIMINARY CONCLUSIONS

The investigation is far from complete. However, several preliminary conclusions can be made:

Preservation of Radiometric Information. Because of the elimination of unnecessary conversions and photographic generations in processing ERTS images by digital image processing techniques, radiometric information is preserved and changed only when correction or enhancement is made. Thus digitally processed images have the potential for Sensor Corrected Radiometry and Scene Corrected geometry.

Preservation of Resolution. Sensor data is maintained and is simply repositioned to achieve geometric correction. Thus, for the same reasons as above, it is likely that image resolution is not degraded by digital image processing.

Accurate Mapping. Predictive mapping computation has shown that digitally corrected images can have geometric errors of about 60 meters (RMS). Further investigation is required for a variety of scene types before this preliminary.conclusion can be confirmed.

Operational Feasibility. Digital processing provides a simple and feasible means of changing both the geometry and radiometry of a scene. Change in sensor performance and characteristics can be compensated for by computer software, and any map projections can be generated by suitable programming and parametric selection.

Throughput. Recent results have shown that four MSS bands can be precision processed in approximately 11.5 minutes of IBM 360/65 CPU time or 30 minutes clock time. This time is comparable with electro-optical processing of ERTS data. Further reduction of these times is projected when an operational system is designed and implemented.

Feasible Technology. Results generated to date suggest the feasibility of digital processing for Scene Correction of ERTS images. Long processing times in the range of hours, which have been previously predicted have not been borne out. Image quality and resolution are maintained. However, further work is necessary to address existing technical problems and refine techniques.

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