Methods for Destriping Landsat Thematic Mapper Images—A Feasibility Study for an Online Destriping Process in the Thematic Mapper Image Processing System (TIPS)

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ABSTRACT: Methods for destriping TM images and results of the application of these methods to selected TM scenes with sensor and scan striping, which was not removed by the radiometric correction during the TM Archive Generation Phase in TIPS, are presented. These methods correct only for gain and offset differences between detectors over many image lines and do not consider within-line effects. The feasibility of implementing a destriping process online in TIPS is also described.

INTRODUCTION

THEMATIC MAPPER IMAGES produced by the Thematic Mapper Image Processing System (TIPS) quite often show radiometric errors in the form of sensor striping, scan striping, or a combination of both. The level of striping may also be a function of cross-track position. These anomalies can be caused by slight errors in the internal calibration system, variations in the response of the sensors, or by random additive noise. In the present study we have investigated possible approaches to correct the radiometric degradation of images and the feasibility of implementing a process in TIPS that will cause minimum impacts on the system.

Two techniques have been considered:

(1) Radiometric equalization reported by Algazi and Ford (1981) using an equalization function which accounts only for variations in offset.
(2) Histogram modification reported by Horn and Woodham (1979), smoothed histogram modification, Kautsky *et al.* (1984).

The discrete histogram modification problem requires the matching of an input histogram to a reference histogram. In our approach the reference histogram is made up from quiet detector responses, and only noisy detector histograms are modified. This method needs an additional decisionmaking process by the production system to select the detectors that cause the striping (noisy detectors).

Radiometric correction using the above methods was applied to 512 × 512 pixel sections from selected scenes with visible striping and proportional representation of water, clouds, and land.

The following Landsat-4 scenes were selected:

Path	Row	Day of the Year
38	40	323/82
25	38	312/82

The second scene was produced after the new R_{min} and R_{max} was installed in the TM Image Processing System (TIPS) (Landsat Science Office, unpublished data, 1984) and was primarily selected for the strong scan striping in band 1. Band Sequential Computer Compatible Tapes (BSQ CCT-ATs) were produced in TIPS from the A-tapes for the selected scenes. The subimage selection and processing was performed in the Digital Image Analysis Laboratory of the General Electric Co. The size of the subimage at this point was picked arbitrarily but cautiously large enough to be able to get good statistical estimates.

The image data treated in this report have already been corrected using the scene content, i.e., gains and offsets based on the absolute calibration have been updated using means and standard deviations of the measured sensor output values for a particular subimage. This correction is based on the assumption that for a large enough image, each subimage has approximately the same probability distribution

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of scene radiance values. Although each subimage has been made to have the same mean and standard deviation (relate the same way to the scene radiance), striping is still present.

DESCRIPTION OF METHODS

RADIOMETRIC EQUALIZATION

In the TM image, each band is scanned by 16 detectors forward and backward such that an assumed sensor variation will produce periodic striping with a period of 16 lines. Assuming that the errors are due to line-to-line variations in the response of the sensors, a model is developed to equalize the response from line j to line k.

If $R(x_i,y_j)$ is the input radiance to be measured and $V(x_i,y_j)$ the sensor voltage output, then the relationship between R and V is of the form

$$V(x_i,y_j) = g_j\ (R(x_i,y_j)) \tag{1}$$

where g_j is a linear or nonlinear function which depends only on the line index j. Thus we assume that the sensor response does not change along the line, an assumption that probably holds for 512 pixels in the scanline.

If we write Equation (1) for line j and k and assume that the intensity R at (x_i,y_j) and (x_i,y_k) is the same, we get

$$V(x_i,y_k) = g_k\ g_j^{-1}(V(x_i,y_j))$$
$$\text{or } V_k = g_{kj}\ (V_j) \tag{2}$$

where $g_{kj}\ (\cdot) = g_k\ (g_j^{-1}(\cdot))$ is the equalization curve from line j to line k. $g_j^{-1}(\cdot)$ is the inverse function of $g_j(\cdot)$.

Since we know from experience that the dominant errors are due to variations in sensor gain and offset, a simple model for the equalization curve would be

$$g_{kj}\ (V_j) = a_{kj}V_j + b_{kj} \tag{3}$$

or a simpler one which accounts only for variations in offset

$$g_{kj}\ (V_j) = V_j + b_{kj} \tag{4}$$

The model described by Equation (4) was used successfully in National Oceanic and Atmospheric Administration satellite images (Algazi and Ford, 1981) where striping is nonperiodic, owing to the use of one sensor per band, but in the present case the model is applied to images with periodic striping.

In the implementation of the model (4), only the line means of the subimage sample are needed to estimate the offset parameter.

The line means contain information about variations in the image content and the sensor response. The image content is modeled as a linear trend which is subtracted from the sequence of line means. The detrended sequence is filtered to remove the noise, which here is the sensor offset, and the difference between the filtered and trend corrected sequence is the error attributed to variations in sensor offset which is used to equalize the radiometry.

HISTOGRAM MODIFICATION

Histogram modification is a method that deals directly with the possible nonlinearity of the sensor transfer functions. The technique requires the construction of a transformation such that the histogram of the original data matches a reference histogram. The problem can be stated as follows: for any input histogram h and a reference histogram h' given on n and m radiance levels respectively, there always exists a transformation $T \epsilon T^m_n$ such that $H_h(x) = H_{h'}(T(x))$, $x \epsilon [0,1]$ and T is given explicitly by $T = H_{h'}{}^{-1}H_h$ where H^{-1} in general denotes the inverse transform of H.

H_h and $H_{h'}$ are the cumulative histograms of h and h' and T is the exact transform matching H_h to $H_{h'}$. In the case of a discrete T transform for all $k = 1,2, \ldots, m$ there exists an integer $j_k \epsilon \{1,2, \ldots, n\}$ such that

$$H_h(j_{k/n}) = H_{h'}(k/m); \tag{5}$$
$$\text{then } j_k = nH_h^{-1} \cdot H_{h'}(k/m)$$

is an integer belonging to $[o,n]$. In general j_k is not an integer, and some rounding procedure is required to define the discrete transform. A lookup table is now constructed by applying the inverse of the function $H_h(x)$ to $H_{h'}(x')$. This lookup table is then used to modify all the sensor values which produced the histogram h. The process is repeated for all sensors.

In our approach, the reference cumulative histogram is constructed only from sensors whose histograms are closely similar (means and standard deviation differ by small amount), and only the cumulative histograms of the sensors causing the striping are matched to the reference histogram. We found that this approach gave better results than matching all detector histograms to a reference histogram made up from all detectors. Selecting the sensors with similar histograms (quiet detectors) might not be totally correct all the time since it is threshold dependent, especially when the algorithm is incorporated into an operational system, but that does not degrade the performance of the algorithm in any appreciable way. Therefore, a criterion for rejection of outlying sensor observations had to be devised to detect noisy sensors.

For this purpose a distribution was developed defined by

$$\tau = \frac{|\delta|}{S} \tag{6}$$

where δ is the deviation of the overall (512×512 scene segment) mean from each sensor mean for the same scene segment and S the standard deviation of the sensor means. Consider the means for each sensor (x_i), $i = 1, \ldots 16$ over a segment of 512 × 512 pixels and let

$$\bar{x} = \frac{1}{16} \sum_{i=1}^{16} x_i,\ S = \sqrt{\frac{\sum_{i=1}^{16} (x_i - \bar{x})^2}{16}} \text{ and } \delta = x_i - \bar{x} \quad (7)$$

Define a mean deviation $MD = \frac{1}{16}\Sigma\tau$ and use it as an outlier criterion i.e., if $\tau - MD > 0$ the sensor is considered an outlier (noisy). A second iteration through this algorithm will narrow further the number of quiet sensors. The algorithm seems to perform fairly well in detecting noisy sensors for the cases that were applied.

In this method only the histogram of the noisy detectors is adjusted to the reference histogram (average histogram of the quiet detectors). The other way would be to adjust the histogram of each detector to an average histogram of all the detectors, which obviously would require more lookup tables.

APPLICATION TO LANDSAT TM IMAGES

Two of the segments selected for correction are part of a band 7 TM scene, path 38, row 40, taken

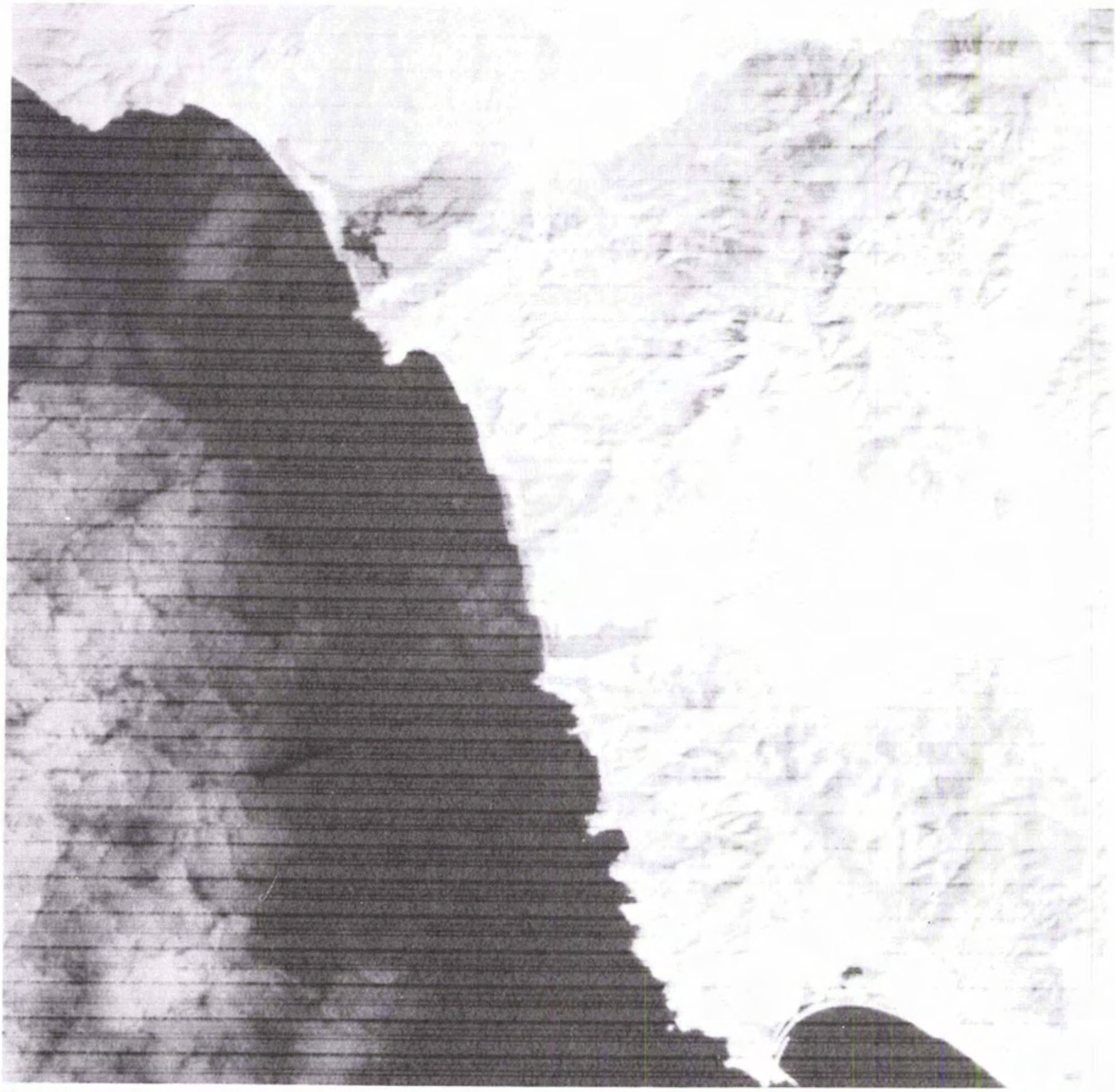

PLATE 1. A 512 × 512 segment from band 7 quadrant 2 Landsat-4 scene, path 38, row 40 taken 19 November 1982.

19 November 1982. They are representative of water, clouds, and land combinations and show where sensor striping is dominant. The subimage illustrated in Plate 1 was extracted from quadrant 2 of the TM scene mentioned above and contains 512 lines and 512 pixels per line.

In Figure 1 the mean radiance for each line is plotted before and after correction by the equalization for variations in offset. It is instructive to see the slow variation of the image content superimposed by the quasi-periodic structure due to the response of the 16 detectors and the removal of the periodic component after correction.

Plate 2 shows the corrected image of Plate 1 by the equalization method. Although the improvement is apparent, some striping is still visible over the clouds, and thin, white lines have substituted for the heavy, dark lines over water in the original image.

Plate 3 shows the corrected image of Plate 1 by the histogram modification method. Some striping is still visible over clouds and water but none over land. Clearly, the performance of the histogram modification method is superior to the equalization for variations in offset. Both methods performed better for smaller (512 × 256) and more homoge-

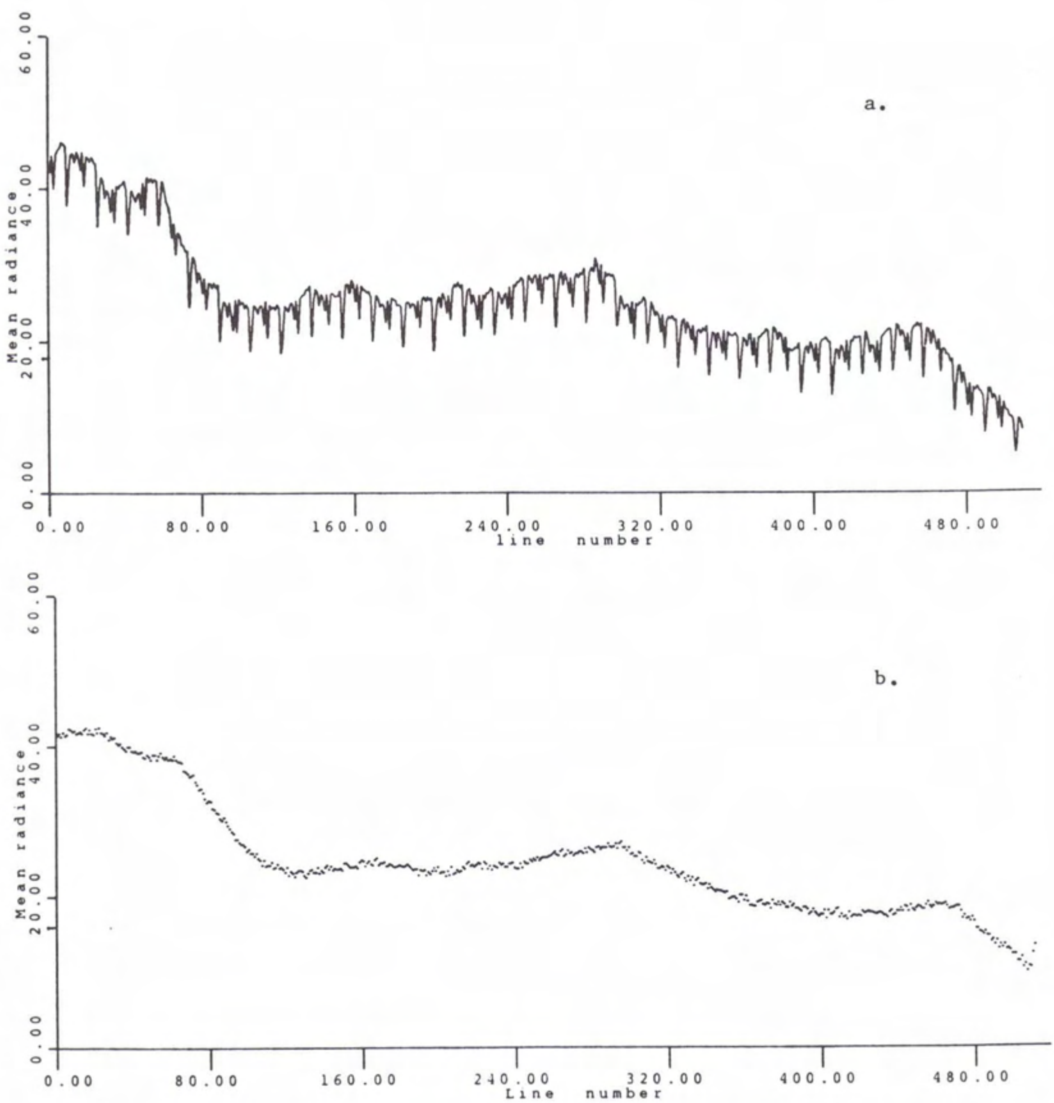

FIG. 1. (A) Line averages for subimage of quadrant 2 in Plate 1. (B) Line averages for subimage of quadrant 2 in Figure 1 equalized for detector offset.

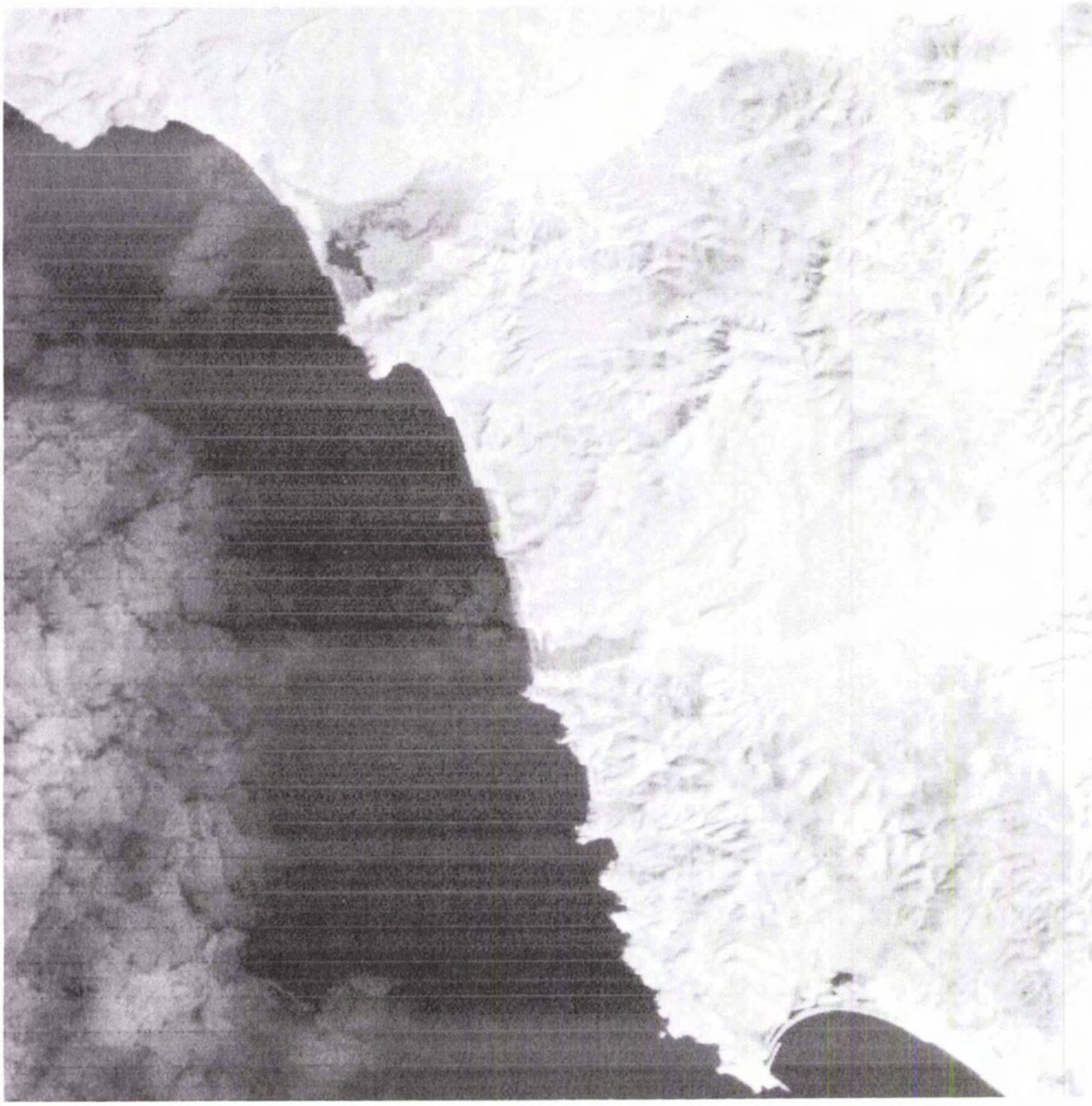

PLATE 2. Subimage of quadrant 2 in Plate 1 equalized for detector offset.

neous areas. Also a subimage (512 × 512) extracted from a TM scene, path 25, row 38, taken 8 November 1982, with dominant scan striping, was corrected by the same methods although not illustrated here.

The histogram modification performed well, but in constructing the reference histogram, the forward and reversed scans were thought of as one 32-detector scan.

The histogram modification technique was selected for the online destriping feasibility study in TIPS mainly for two reasons: (1) its performance, and (2) our previous experience with such a method in destriping MSS imagery in the General Electric Digital Image Analysis Laboratory.

WHERE DOES THE DESTRIPING PROCESS FIT IN TIPS

The goal is to produce final products such as LBR film and CCTs with as little as possible striping. Final products are generated during the TM Final Product Generation (TFG) process with input from TM Initial Product Generation (TIG), and therefore a possible scenario is to destripe the imagery re-

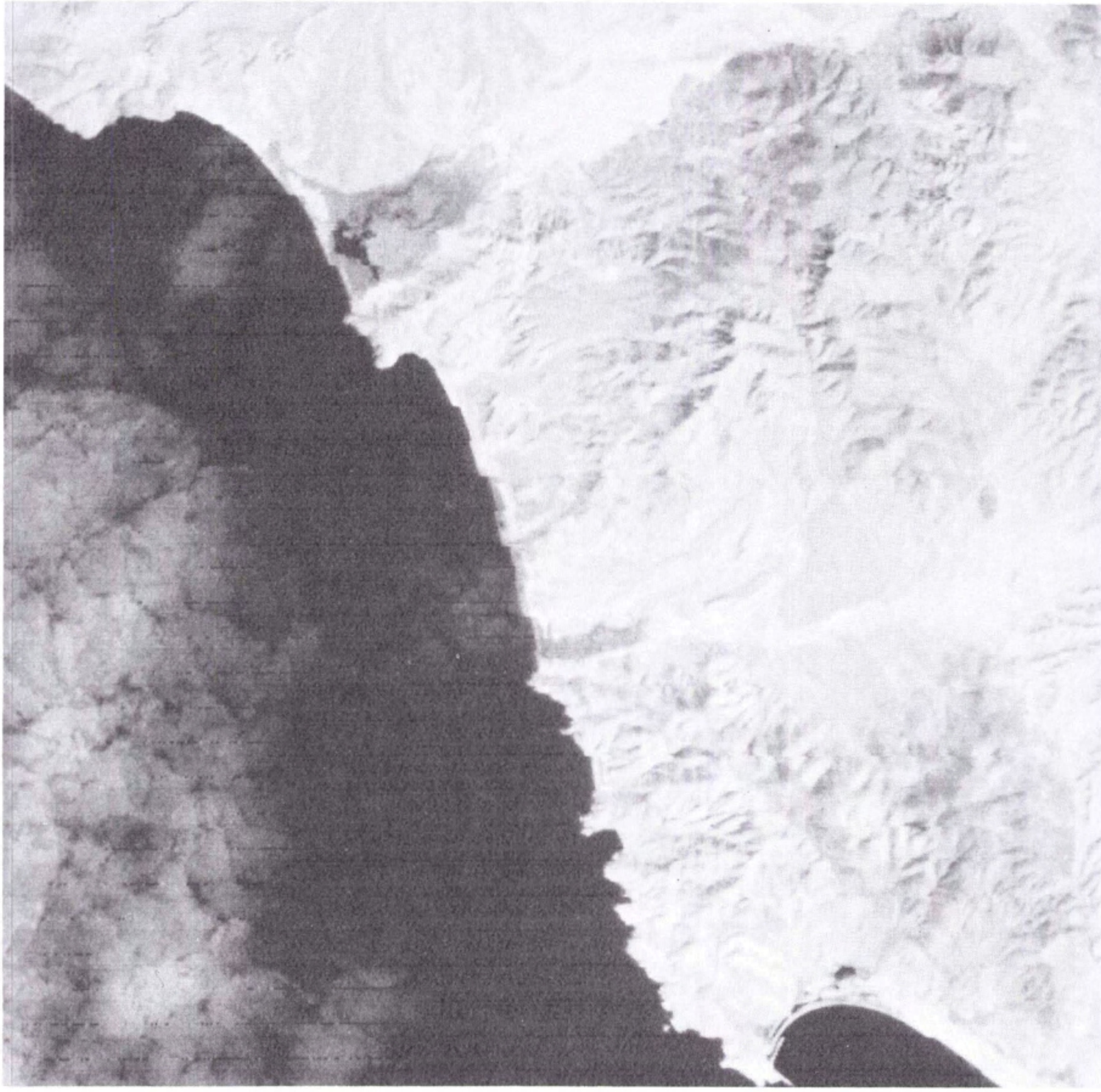

PLATE 3. Subimage of quadrant 2 in Plate 1 destriped by histogram modification.

siding on disks after the TIG ingest. Figure 3 represents a high-level data flow for such a process. Image data are read off the disks to the destriping process, corrected, and returned back to disks. Utilities are already in existence to perform read-write functions. About 320 lines of image data at a time can be transmitted to the destriping process. One is forced into this design due to the fact that the destriping process takes much more time (21 minutes per scene, VAX 11/780 time) than the geometric correction process (7 minutes per scene). A disadvantage of such a design is that the processes following destriping such as geometric correction and product generation will remain idle until destriping is completed. Therefore the destriping process has to be rapid so that it will not affect the production and turnaround performance of TIPS.

SYSTEM IMPACTS

At the present time, the destriping engineering code (nonoptimized) requires roughly three minutes to process one scene, one band. This estimate is derived by summing up the processing times of all the 512 × 512 segments that comprise the whole scene (Figure 4). An additional processing to smooth the boundaries of the 512 × 512 segments will in-

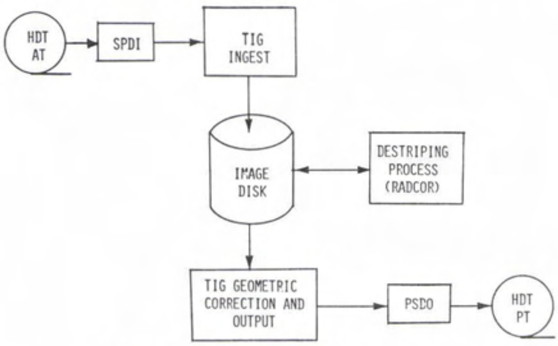

FIG. 2. TIG/RADCOR DATA FLOW

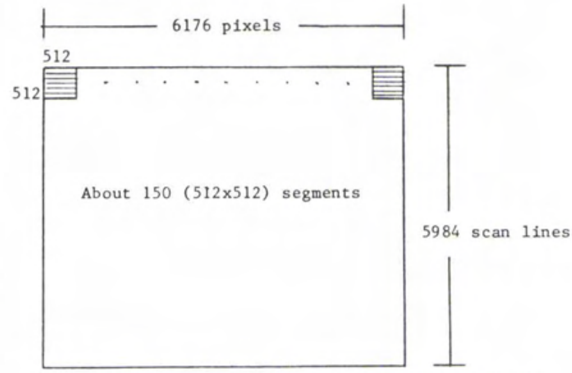

FIG. 3. TM scene divided into 512 × 512 segments.

crease some more the three-minute estimate per scene. The computer time for such a process is not taken into account in the present study.

Figure 5 depicts a time sequence diagram for ingest, correction, and output requirements. To destripe and output three scenes will take about 77 minutes, compared to 28 minutes needed without destriping, or an increase of processing time by almost a factor of three. The time estimate for destriping is based on the assumption that all bands need to be corrected. From QA experience with the 241 mm film, we know that striping is present only in a few bands. Realistically the 21-minute (Figure 5) destriping estimate for one scene in all bands will drop down to about 14 minutes, which is the time required to correct one scene in five bands. To correct three scenes in five bands, the required time is 56 minutes versus 28 minutes needed without destriping (ratio of 2 to 1). A further time reduction is also possible in the destriping process when the present engineering code is optimized to become operational. With all possible improvements the process still requires a sizeable amount of time.

To process 50 scenes through TIG using destriping will take about 21 hours, which is 13 hours more time than the normal processing. The system will no longer meet turnaround requirements. The next observation is that sensor striping is not as big a problem for Landsat-5 as it is for Landsat-4, and although scan striping is still present in both sen-

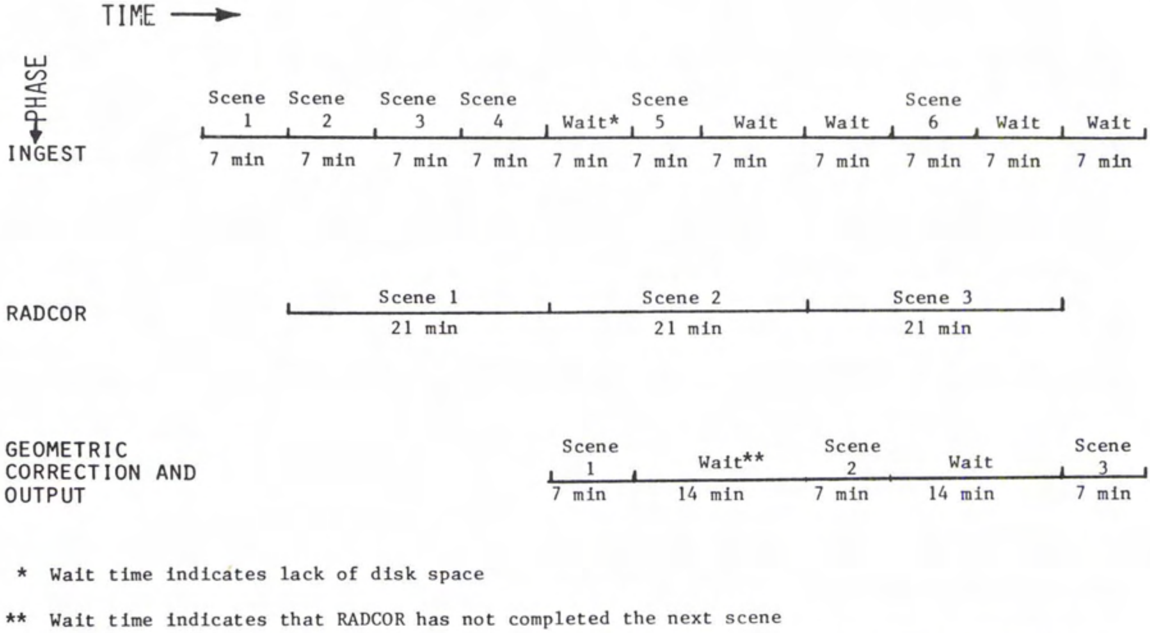

FIG. 4. Timing sequence for destriping process (based on overlapped A-scenes and 4 disk pairs available).

sors, it is not serious enough to warrant an online destriping process.

The recommendation for destriping is to be used as an offline process for special requests.

ACKNOWLEDGMENTS

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ANNOUNCEMENT AND CALL FOR PAPERS

International Society for Photogrammetry and Remote Sensing Commission V Symposium Real-Time Photogrammetry—A New Challenge

Ottawa, Ontario, Canada
16-19 June 1986

This Commission V Inter-Congress Symposium of ISPRS—sponsored by the International Society for Photogrammetry and Remote Sensing and The Canadian Institute of Surveying in cooperation with the National Research Council of Canada; Energy, Mines and Resources Canada; and Environment Canada—will provide a forum for the exchange of ideas and for the presentation of reports on a wide range of topics related to non-topographic photogrammetry. The general development in this field since the 1984 ISPRS Congress in Rio de Janeiro will be reviewed and preparations will be initiated for the Commission V program at the 1988 ISPRS Congress in Kyoto.

The theme, "Real-Time Photogrammetry—A New Challenge," reflects the current high potential of real-time computer processing and its timeliness in non-topographic photogrammetry. The theme was chosen to emphasize the current trend towards the implementation of photogrammetry within the real-time constraints of processes and operations monitored or controlled in three-dimensional space. It is hoped that the meeting will demonstrate that photogrammetric principles can be used as viable elements of sophisticated systems in areas such as engineering control, robotics, and machine vision. Papers on related methodologies and instrumentation are most welcome.

Although the theme underlines a single subject, it does not preclude the discussion of other topics pertinent to the Commission V mandate. Papers are invited in the following areas which correspond to the current general activities of Commission V:

- Analytics of non-topographic photogrammetry
- Low altitude aerial photogrammetry
- Unconventional technologies in close-range photogrammetry
- Close-range photogrammetry in industry and applied science
- Biostereometrics
- Digital and real-time photogrammetry
- Architectural photogrammetry

Those wishing to present a paper should submit a brief outline by *1 October 1985* to

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