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June 1982

Technical Report

AUTOMATIC SEGMENT MATCHING ALGORITHM THEORY, TEST AND EVALUATION

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16. ABSTRACT

This report describes the results of the AgRISTARS' Domestic Crops and Land Cover Scene-to-Map Registration Task. The purpose of this study was to automate the U.S. Department of Agriculture's process of segment shifting and obtain results within one-half pixel accuracy. Given an initial registration, the digitized segment is shifted until a more precise fit to the Landsat data is found. The algorithm, ASMA (Automatic Segment Matching Algorithm), automates the shifting process and performs certain tests for matching and accepting the computed shift numbers. Results of this study indicate the algorithm can obtain results within one-half pixel accuracy.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NATIONAL SPACE TECHNOLOGY LABORATORIES

EARTH RESOURCES LABORATORY

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1. INTRODUCTION

1.1 BACKGROUND

The work reported here was carried out as part of the AgRISTARS Domestic Crops and Land Cover project (DCLC) Scene-to-Map Registration Task. The objective of the task was to develop an algorithm that would automate the United States Department of Agriculture/Statistical Reporting Service (USDA/SRS) process of segment shifting.

Much of the USDA/SRS crop area estimation approach depends on a set of sample segments for developing crop signatures from Landsat data. The information from the spectral data is used with ground truth data to develop regression estimators. The registration of the sample segments to the raw Landsat data is an essential step for minimizing the mean square errors from the regression estimation process.

Currently, an initial registration of the segment data is obtained using a least-squares fit based on selected control points. The initial registration gives an adequate fit on a global basis, but on a local basis more precision can be obtained. The USDA/SRS presently accomplishes this by manually shifting the segments in the locality of the initial gross registration until a "good" fit can be visually detected.

1.2 USDA/SRS SEGMENT SHIFTING PROCEDURE

Once the segments are digitized from either aerial photographs or topographic maps, the coordinates are converted to UTM using coefficients from a segment network file (Ozga, et.al. 1977). The UTM coordinates are transformed to latitude and longitude and then to Landsat lines and columns using mapping coefficients from a segment calibration file. Hard copies of the digitized segment boundaries are obtained from a printer, as well as grey level prints of the Landsat imagery, usually bands 5 and 7. The print of the registered segment boundary is overlaid to the Landsat print at the location of the initial registration. The boundary plot is then shifted around until a better fit is found. The new fit is recorded as the shift necessary to correct the original registration. For example, the segment boundary location may have to be shifted one column to the left and two lines up. This shifting process is carried out for all sample segments before any Landsat data is processed for spectral signature development.

The registration errors are assumed to be pure translation errors by the USDA and were treated as such in this study. For this reason, the process is restricted to shifting in the row and/or column directions.

An example of a segment boundary plot overlaid to raw Landsat data is illustrated in Figure 1. This picture shows the initial registration of the segment boundary to the raw data. The poor correlation between the two images is readily apparent. Figure 2 illustrates the segment boundary location for the same segment after it has been shifted. This particular segment required a shift of -1 rows and -3 columns from the original registration to locate it correctly.

ORIGINAL REGISTRATION - USDA

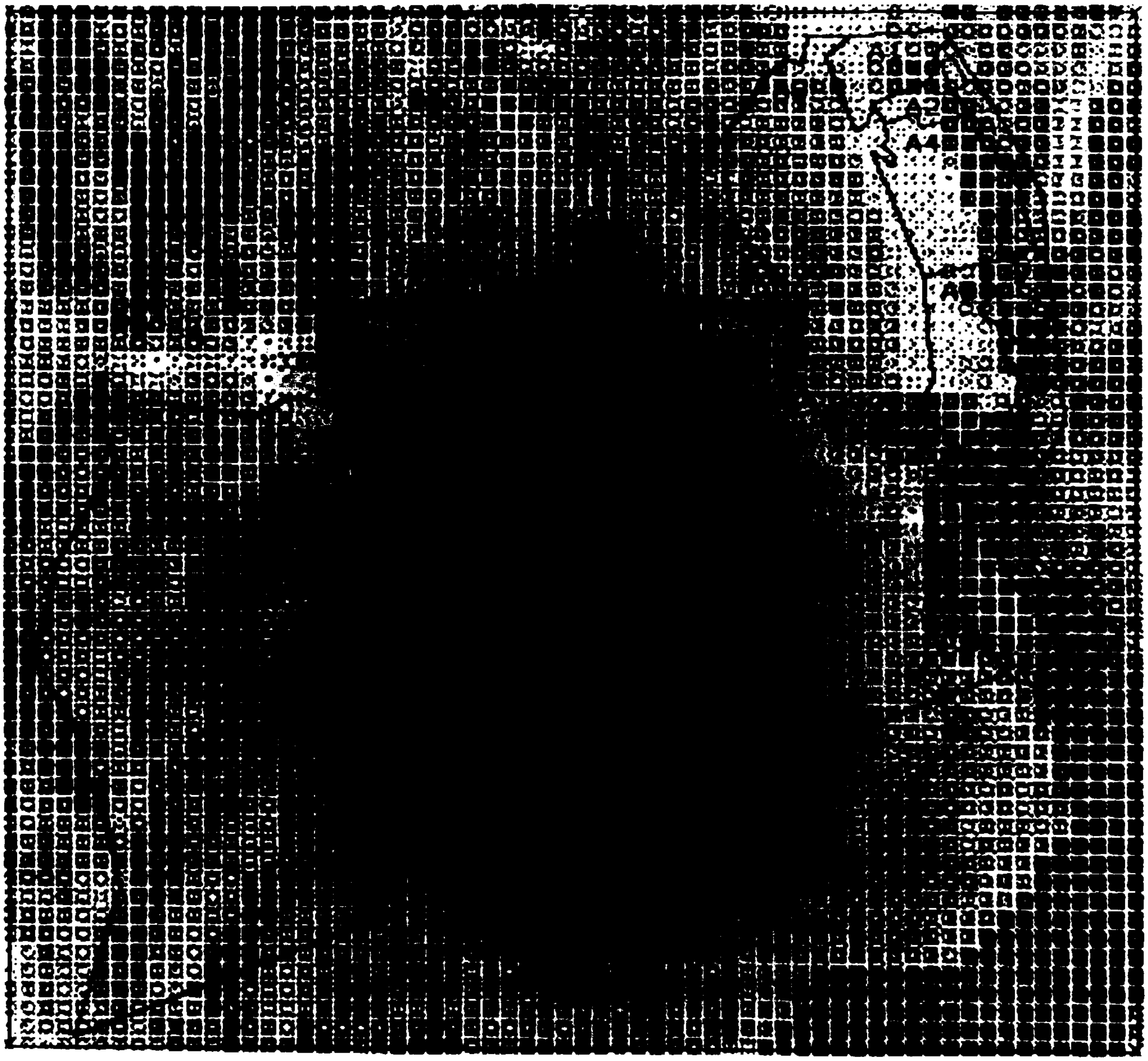


FIGURE 1

Figure 1. Initial Registration of Segment Boundary to Raw Data

AFTER SHIFTING (ASMA)

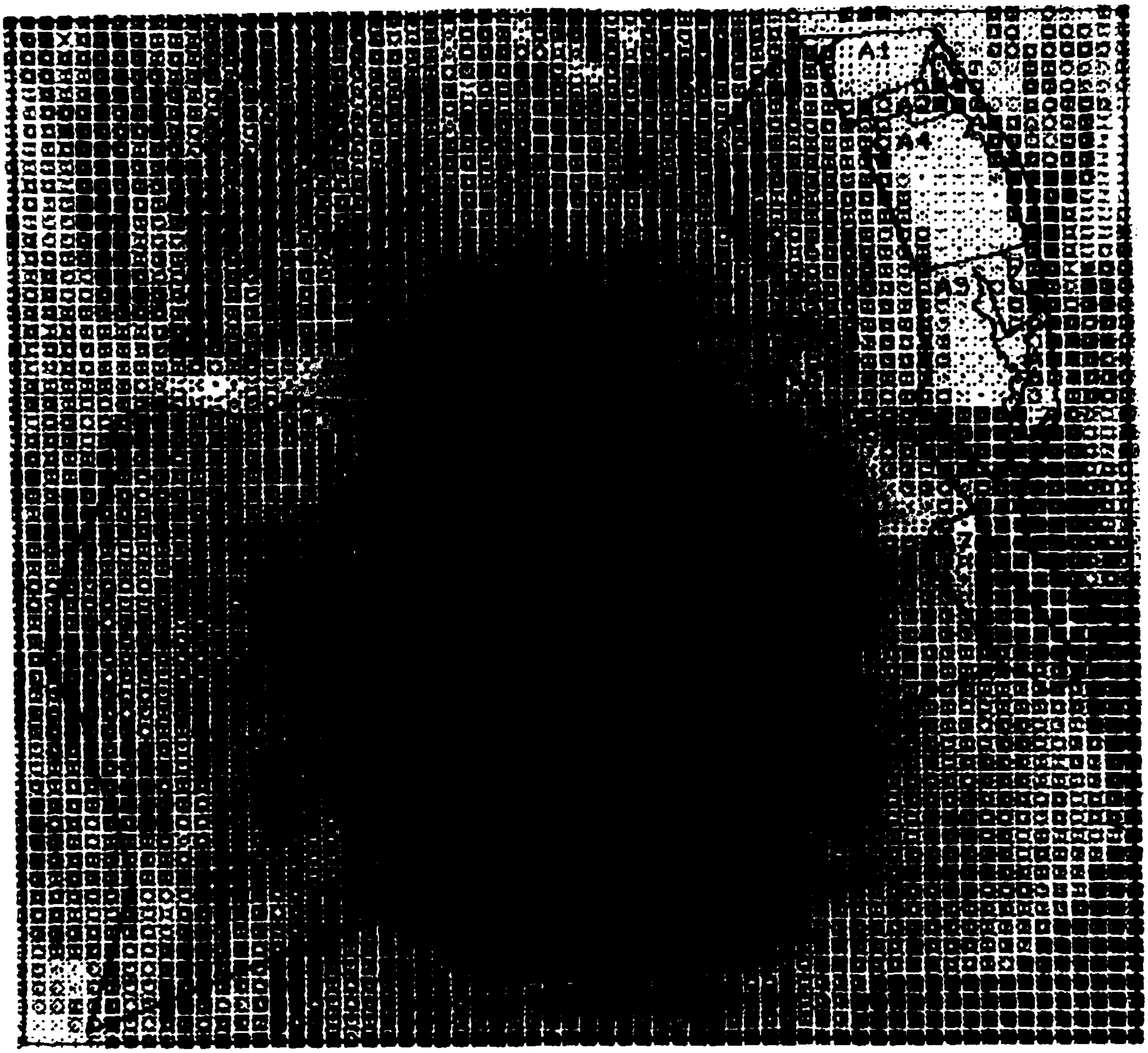


FIGURE 2

Figure 2. Segment Boundary After Shifting

2. THE AUTOMATED SEGMENT MATCHING ALGORITHM (ASMA)

2.1 SEGMENT DATA PREPARATION

2.1.1 INITIAL REGISTRATION OF SEGMENTS

The shifting program requires the initial registration of the segment as a reference point, as does the manual process. Therefore, the same coefficients as described in Section 1.2 are used by the program to convert digitizer coordinates to UTM, then to latitude and longitude before they are converted to Landsat lines and elements. Once the segment vertices are in Landsat coordinates, the segments can be reconstructed on a grid.

2.1.2 'RESAMPLING' OF SEGMENT BOUNDARIES TO LANDSAT DATA

It was decided at the onset of this study to work on a quarter-pixel resolution cell size (Graham, 1981). This cell size was chosen in order to work with half row and half column precision. The original USDA objectives required that the algorithm be correct within a half pixel. Therefore, before resampling the segment boundary to the Landsat reference, the segment line and element vertices are doubled. (The program works on an array which is twice as long and twice as wide as the original input cell array.)

A grid is constructed with each cell side representing one half pixel. The program then interpolates between vertices to obtain the cells to which the boundaries are remapped.

2.1.3 THE RECONSTRUCTED SEGMENT GRID

The array containing the resampled segment boundaries is mapped as follows: a 1 represents a boundary, a 0 represents points outside the segment, and the remainder of numbers represent field numbers. A 1 has been added to the field numbers in the program to distinguish a field value of 1 from a boundary. These values are stored in memory during run-time. The program numbers the field after the boundaries are constructed. An example of a reconstructed grid is shown in Figure 3. (The field numbers are not shown.)

2.2 LANDSAT DATA PREPARATION

The Landsat bands 5 and 7 data is extracted for the area encompassing the segment with an additional 5 pixels on each side. These padding pixels define the area in which the segment is to be shifted. It was decided to use 5 pixels because the registration errors were never larger than 5 pixels[1] in the sample data sets. This area differs from the 10 pixel shifting area discussed by Graham (1981); using the 5 pixel shifting area also decreases the size of the program as well as run time.

2.2.1 EDGE ENHANCEMENT OF LANDSAT DATA

The segment shifting program uses edge enhanced data to locate the segment boundaries. The data is transformed to a gradient image using the same equations given by Graham (1981). These are given by:

$$g_1 = \sum_i \left| x_{0i} - x_{1i} \right| /2 \qquad (1)$$

$$g_2 = \sum_i \text{sqrt} \left(\left(\frac{x_{0i} - x_{2i}}{2} \right)^2 + \left(\frac{x_{1i} - x_{3i}}{2} \right)^2 \right) \qquad (2)$$

$$g_3 = \sum_i \left| x_{0i} - x_{3i} \right| /2 \qquad (3)$$

---

1. For a 57m resolution, this corresponds to 285 meters.

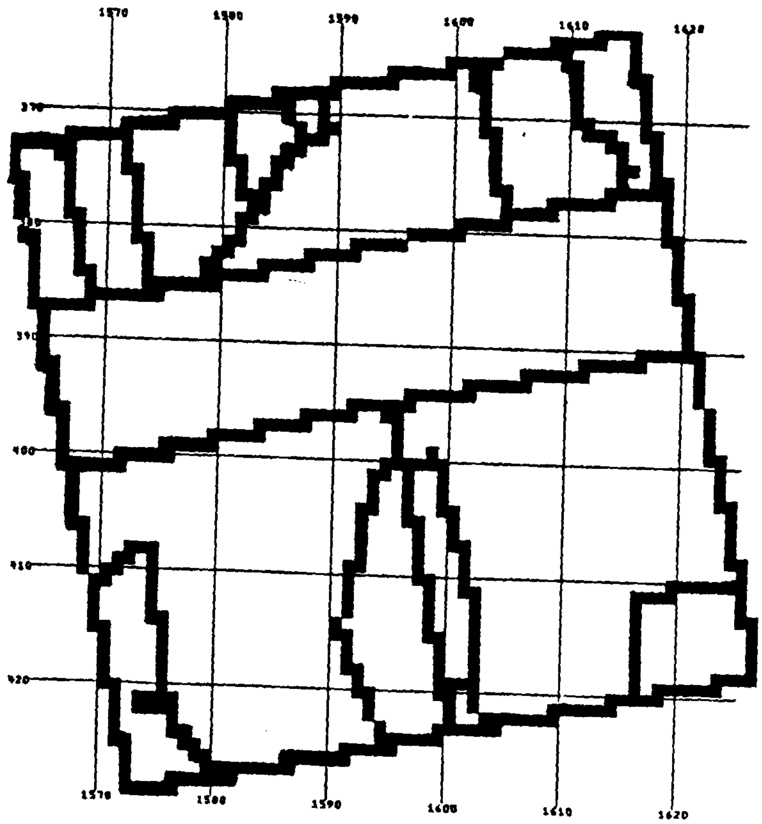


Figure 3. Print of Sample USDA/SRS Segment Based on Algorithm Reconstruction

Where:

X_{hi} is the Landsat reflectance value for location L_h, band i.

h = 0, 1, 2, 3 denotes location, illustrated in Figure 4a below.

i = bands 5 and 7 of Landsat.

L_1	L_2
L_0	L_3

Figure 4a. Original Cell Locations

The values in (1), (2), and (3) are output to an expanded grid, Figure 4b. This grid represents the quarter pixel cell size discussed in Section 2.1.2. The original cell locations, from Figure 4a, are shown in their new location.

	L_1		L_2
	g_1	g_2	
	L_0	g_3	L_3

Figure 4b. New Cell Locations

The g values are set to 10 if their computed value is greater than 10. This saturation value is used to prevent extremely large values of the gradient from masking out the effect of more subtle but significant changes in land cover. This effect will become more readily apparent in the ensuing discussion of the algorithm.

The above equations show the output values based on (0) as the pivot. The algorithm slides this 2x2 window to the next pixel, L_3 and computes (1), (2), and (3) with it as the pivot. The process is carried out for all pixels in the search area. The original cell locations are not assigned values by this process; they are assigned the mean value from the neighboring 8 cells (or 5 cells at the file edge).

This gradient image is used by the algorithm for the segment shifting and statistics computations. The raw Landsat data is no longer required after this point.

2.3 THE SEGMENT SHIFTING AND MATCHING PROCEDURE

2.3.1 SHIFTING THE SEGMENTS

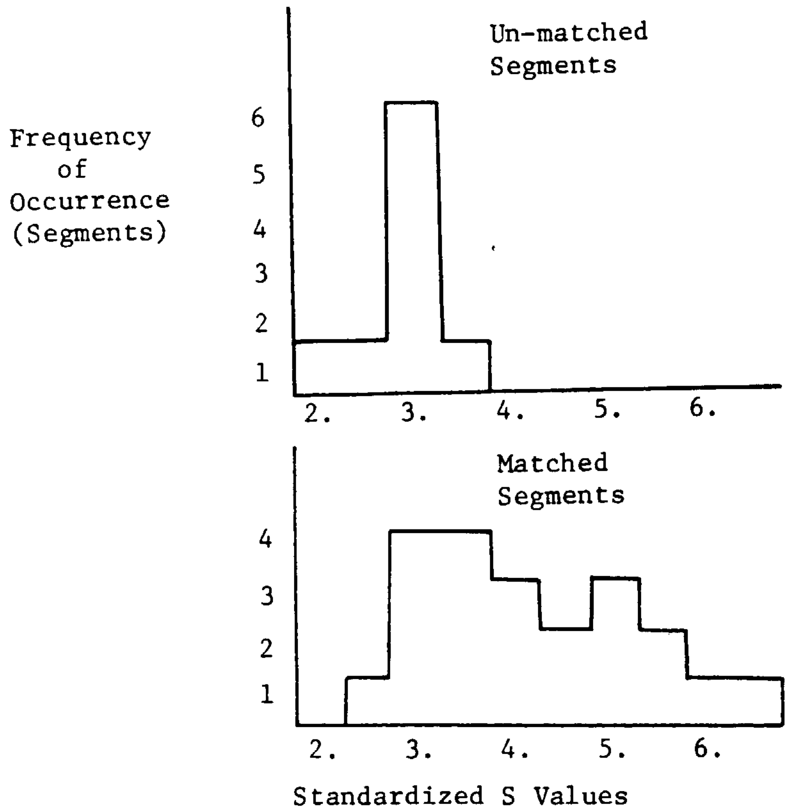
The segment array is indexed to the gradient array at the location of the initial registration. The gradient values are summed along the boundaries within and around the segment. That is, the boundary file is used as a mask into the gradient file. This can be stated mathematically as follows:

$$
\begin{aligned}
\text{Let} \quad b_{ij} &= 1 \text{ for a cell boundary} \\
&= 0 \text{ elsewhere} \\
\text{and,} \quad g_{ij} &= \text{cell gradient} \qquad (4) \\
\text{then,} \quad s_{ij} &= \sum_{i,j} b_{ij} * g_{ij}
\end{aligned}
$$

Where s_{ij} is the matching coefficient. The value s_{ij} is standardized to a mean of 0, and standard deviation of 1. This is done to obtain a relative matching coefficient at each cell. The segment boundary is shifted over the entire search area and an s value computed at each shift.

The s value is directly proportional to the amount of agreement between the two images. Therefore, the maximum s value is taken as the best match and the corresponding shift is recorded. The shift is accepted only if s is above a certain threshold.

An empirical study was performed on several data sets to determine a threshold value against which to compare s. This study used histograms of the s values for all segments within a given data set. The shifts from the algorithm were determined to be either matches or non-matches by comparing the algorithm results to the manual shifting (USDA/SRS) results. The histogram, Figure 5, shows the distribution of s values for the accepted and unaccepted shifts. The RMS errors were computed for six data sets using s values from 3.2 to 3.6 in order to find a threshold value for the first stage acceptance test. The optimum value for the threshold, 3.4, was for the shift having the smallest RMS error. Any segment shifts with an s value less than 2.0 are discarded since these shifts do not appear to be significantly different from other shifts in the sample.



S: < 2.0 Discarded
2.0-3.4 Enter Second Stage
> 3.4 Accepted in First Stage

Figure 5. Bar Histogram Representation of Standardized S-Values for Sample of 30 Segments

2.3.2 THE SECOND STAGE TEST

Those segments with shifts not meeting the required threshold value on the first stage test are automatically entered into a second stage test. The second stage test examines the homogeneity of pixels within field boundaries. The program uses the gradient output array to obtain a measure of within field variability for each shift. Basically, the gradients represent how similar adjacent pixels are; so by taking the sum of the squared gradients within each field, a measure of homogeneity is obtained.

Let: g_{ijk} = gradient value for pixel i, j, in field k.

$$d_k = \sum_{i,j} g_{ijk}^2/n \qquad \text{Dispersion for field k; n is number of non-border pixels in field.} \tag{5}$$

$$d_s = \sum_k d_k \qquad \text{dispersion value for shift } s_{ij}. \tag{6}$$

The second stage test uses the following statistic to decide which shift is best:

$$v = \max_L \left[\frac{s}{d_s} \right] \tag{7}$$

The ratio of the s value from the first stage to the d_s value is maximized. This value gives the shift with the largest gradient along the boundaries, relative to the dispersion within the boundaries. The set L is the set of all segment shifts from the first stage which had s values in the 2.0-3.4 range.

The shift value recorded from the second stage is that value of the shift associated with v.

2.4 FINAL ACCEPTANCE TEST

Some criteria must be used to determine if the results of the shifting process are acceptable. The criteria used in ASMA is based on a technique outlined by Graham (1981).

The acceptance test is based on the assumption that the shifts accepted in the first stage test make up a sample of a population of 'reliable' shift values (based on s value).

By constructing a 'confidence interval' around the mean of this population an acceptance region is established for shift values from the second stage test. The current test is to accept the second stage shift if the shift value for both the row and column is within:

$$\bar{Y} \pm 1.7 \hat{\sigma}_y \qquad (8)$$

where $\bar{Y}$ is the mean shift from the first stage and y is the standard deviation.

In summary, all values from the first stage test are accepted if they are greater than 3.4, otherwise, the value from the second stage test is accepted if they are in the acceptance interval (8). A flow diagram of ASMA is shown in Figure 6.

3. TEST AND EVALUATION

The algorithm developed by Graham and further refined here was based on a Landsat 2 Kansas data set (21980 - 16264) from 1981. The algorithm was tested and further refined on another set of 5 Landsat Scenes (Table 3.1).

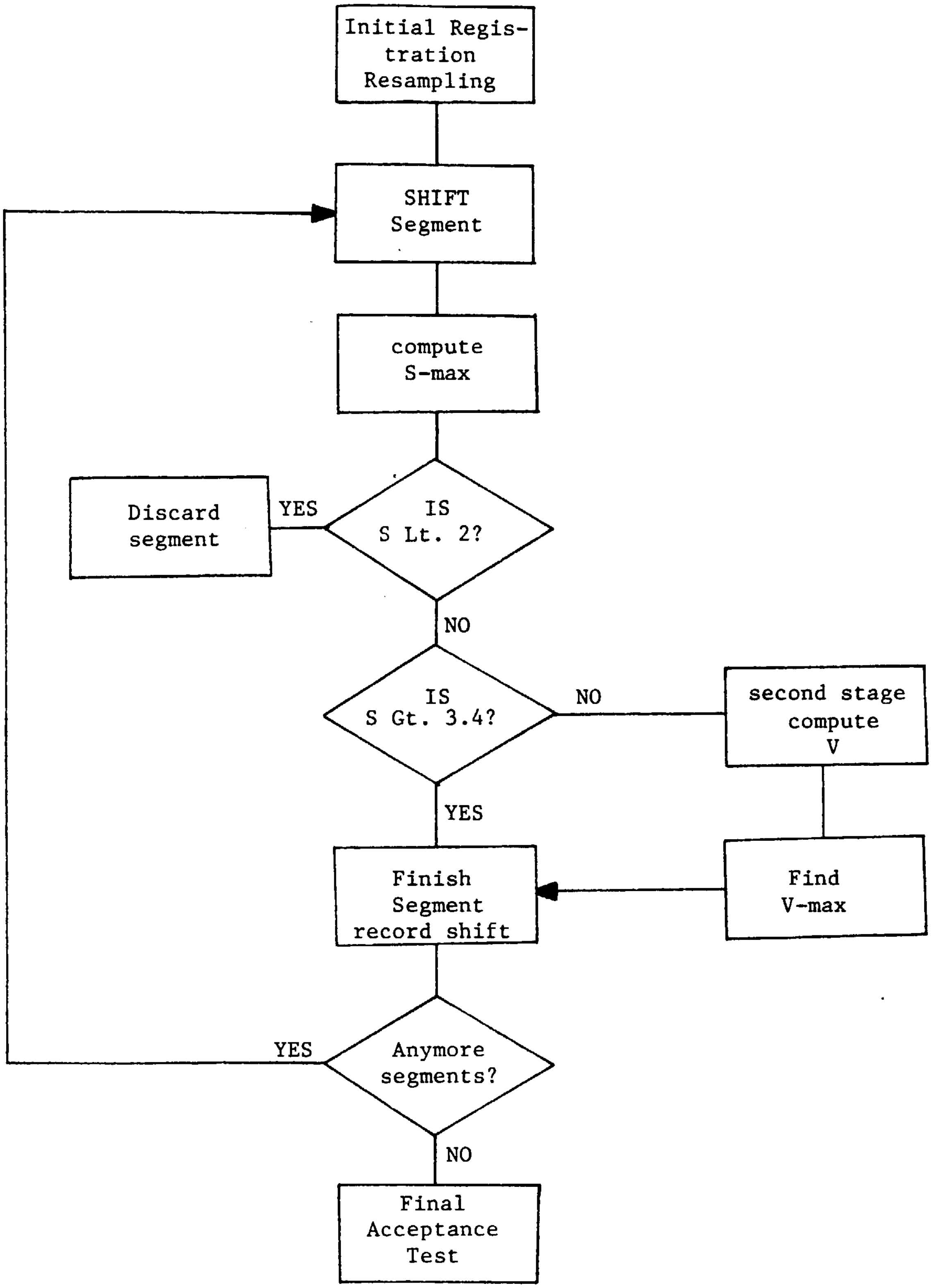


Figure 6. Flow Diagram of ASMA

Site	I.D.	Scene No.	No. Segments
Kansas	(1)	21980 - 16264	20
	(2)	22287 - 16313	39
Missouri	(1)	22370 - 15502	9
	(2)	22370 - 15504	8
	(3)	22371 - 15560	29
	(4)	22371 - 15563	16
			121 TOTAL

Table 3.1 - Set of Six Scenes Used for Testing

3.1 ERROR ANALYSIS

Manual shifting results were obtained from USDA/SRS on all 6 scenes. There were at least 2 estimates (of the row and column shift numbers) obtained from 5 of the scenes in order to estimate the repeatability. The manual shifting results are listed in Appendix B. The mean shift value was used as an estimate of the true value in order to evaluate the algorithm results. Table 3.2 gives the results of the manual shifting error analysis. This is given by:

$$\hat{\sigma}_e^2 = \frac{\sum_{i=1}^{n} (x_1 - x_2)_i^2}{2\ (n - 1)} \qquad (9)$$

where X_1 and X_2 correspond to the independent estimates by persons 1 and 2, and n is the number of segments.

Scene	Row	Column
Kansas		
(1)	.41	.33
Missouri		
(1)	.23	.26
(2)	.20	.25
(3)	.45	.30
(4)	.13	.32

Table 3.2 - $\hat{\sigma}_e$ For Manual Shifting Results (In Pixels)

The results from the segment shifting algorithm are listed in Appendix A. A summary of the error analysis is given (in meters) in Table 3.3. The root mean square (rms) error is given by:

$$\hat{\sigma}_r = \left(\hat{\sigma}_X^{\,2} - \frac{1}{2}\hat{\sigma}_e^{\,2}\right)^{\frac{1}{2}} \qquad (10)$$

where:

$$\hat{\sigma}_X^{\,2} = \sum_{i=1}^{n} (X_{ri} - \bar{X}_i)^2 \Big/ (n-1) \qquad (11)$$

And: X_{ri} = the ASMA shift for segment i, in the column direction.

$\bar{X}_i$ = the mean manual shift for segment i

n = number of segments

Similarly, Y_{ri} and $\bar{Y}_i$ are computed for the row direction.

3.2 DISCUSSION OF RESULTS

The initial aim to get results with half-pixel (28.5m) accuracy was met in most cases. Referring to Table 3.3, the 28.5 meter requirement was met in all cases for the row RMS and in 4 out of 6 cases for the column RMS. The overall RMS errors, 18.89m and 25.23m did meet the requirement. The total RMS error, calculated as:

$$\hat{\sigma}_{TOT} = \left(\hat{\sigma}_x^2 + \hat{\sigma}_y^2 \right)^{\frac{1}{2}} \tag{12}$$

was also with the 40.30 meters required.

Of the total 121 segments, 90 were accepted. This gives an acceptance rate of about 74.4%.

The RMS error is proportional to the number of segments accepted, so the more segments accepted, the larger the RMS errors. Some work was done in trying to optimize the acceptance region and the 1.7 used was a rough approximation to a Z value for a 90% confidence region. There is no assumption made about the distribution of the shift numbers. The value used may also be made optional.

Several iterations of the algorithm showed that when Z was less than 1.7 too many segments were not accepted and at larger values, too many were accepted--inflating the RMS errors.

The results indicated also that ASMA had a slightly greater shift than the average manual shift, Table 3.3. This result had no immediate significance and may disappear with further testing of the algorithm. It was noticed in analyzing the results that the shifts were almost always negative, that is, the shift was usually up and to the left. This fact may just be an anomaly of the USDA/SRS registration procedure or peculiar to the areas of study, i.e., Kansas and Missouri.

Table 3.3 - RESULTS OF ASMA ERROR ANALYSIS BASED ON USDA/SRS MANUAL SHIFTING ESTIMATES

SCENE	No. of Segments TOTAL	No. of Segments ACCEPTED	RMS (In Meters), (Based on Accepted Segments) ROW	COLUMN	TOTAL	Average Shift Differences[1] ROW	COLUMN
Kansas (1)	20	18	18.81	30.09	35.49	-.194	-.292
(2)	39	31	19.62	21.75	29.29	-.167	-.158
Missouri (1)	9	6	18.16	15.15	23.65	-.167	-.230
(2)	8	6	25.75	33.42	42.19	-.167	-.167
(3)	29	17	17.21	24.73	30.13	-.164	-.289
(4)	16	12	16.38	28.24	32.64	-.167	-.458
	121	90	18.86	25.21	31.62	-.172	-.256

1 Diff = (USDA/SRS shift - ASMA shift) in pixels

The correlation between the ASMA results and manual results was also examined. The correlations (r) are shown in Table 3.4.

Site		Row Shift r	Column Shift r	Sample Size n
Kansas	(1)	.897	.929	18
	(2)	.793	.932	30
Missouri	(1)	.858	.962	6
	(2)	.224	.506	6
	(3)	.946	.924	16
	(4)	.977	.947	12

Table 3.4 - Correlations between manual and ASMA results

In all cases, except Missouri (2), the correlations were high. The Missouri (2) scene was also the one with the largest RMS errors; the column shifts not being within the accepted half pixel accuracy. This scene gave some problems earlier in the development of the first acceptance test, in that only 1 of the 8 segments were accepted. The test was made less stringent and thus 6 of the 8 segments were accepted. The results from this scene may be due to one segment in particular, or due to the small sample size (8). When segment 6344 is discarded, the RMS errors become 23.357, 24.682, and 35.386 meters for row, column, and total, respectively. These errors then became acceptable.

This particular scene Missouri (2), had only 4 segments making up the statistics for the final acceptance test. This is perhaps a limitation of the program and something which could merit further study. It is also deemable that the segments from this scene did not lend themselves to the characteristics making the other scenes successful, i.e., good boundary delineation. Segment 6344 is shown in Figure 7.

ORIGINAL REGISTRATION USDA

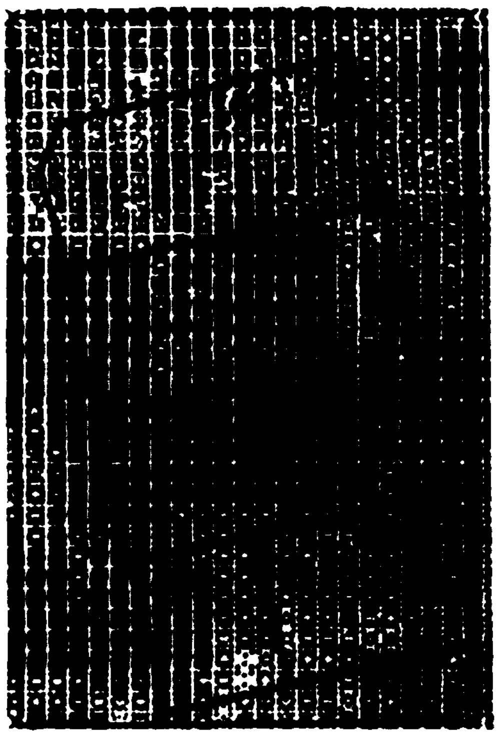


FIGURE 7a

AFTER SHIFTING- ASMA

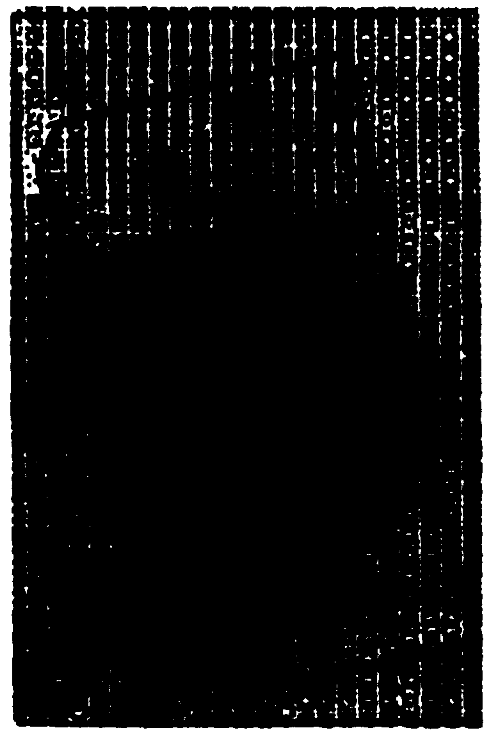


FIGURE 7b

AFTER SHIFTING - USDA

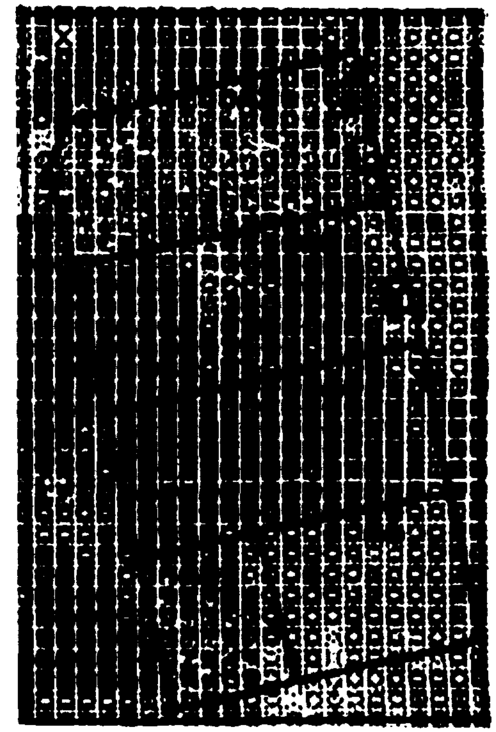


FIGURE 7c

Figure 7. Segment 6344

All in all, the algorithm gave relatively good results. Some of the segments and their shifted boundaries are shown in Figures 4 to 11. Segment 6450, Figure 1 and 2 gave good results in the area of fields A1, A4 and A5. The narrow area to the right of these fields was found to fit quite well after shifting by ASMA. Figure 8 shows a segment which not only matched up well but also gave the exact same shift as the USDA/SRS manual shift.

Figure 9 is a good example of a confusion segment. This segment, incidentally, had the highest differece in shift from the USDA/SRS estimate [See Appendix A - segment 7150, Kansas (2)]. The ASMA shift is shown in Figure 9b and the USDA/SRS shift is shown in Figure 9c. The confusion lies in the fact that the USDA/SRS fit looks better but at the same time, Fields C2 and C3 are both winter wheat. The ASMA shift shows C2 and C3 as being alike. The USDA/SRS shift shows them as different. D1 and D2 are also winter wheat (on the crop code list). These show up as being two dark fields in Figure 9 as opposed to the two light fields, C2 and C3, also representing winter wheat. This segment could probably have been eliminated from the error analysis because of the confusion but was kept instead in order not to bias the results (since not all segments were visually checked this closely).

Figures 10 a,b show another segment which was matched quite well and which also resulted in the same shift as the USDA/SRS. Figures 11 a,b,c show another good segment shift in which ASMA was a quarter-pixel off from the manual estimate (This difference is really too small to see in the figures attached.) In this case, ASMA happened to agree exactly with one USDA/SRS estimate, but was different from the average of the two USDA/SRS estimates.

3.3 RECOMMENDATION

More data sets need to be tested in order to further evaluate the algorithm. Also, some further research should be done on the final acceptance test. It appears that for scenes with large samples of

ORIGINAL REGISTRATION - USDA

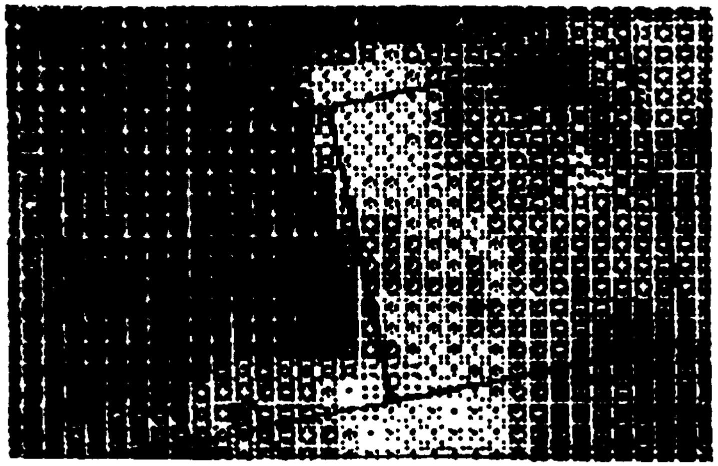


FIGURE 8a

AFTER SHIFTING (USDA) ASMA

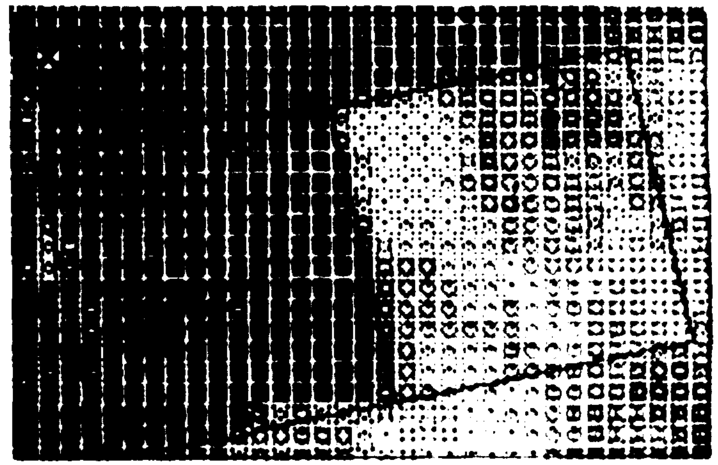


FIGURE 8b

Figure 8. Matching Segment Which Gives Same Shift As Manual Shift

ORIGINAL REGISTRATION

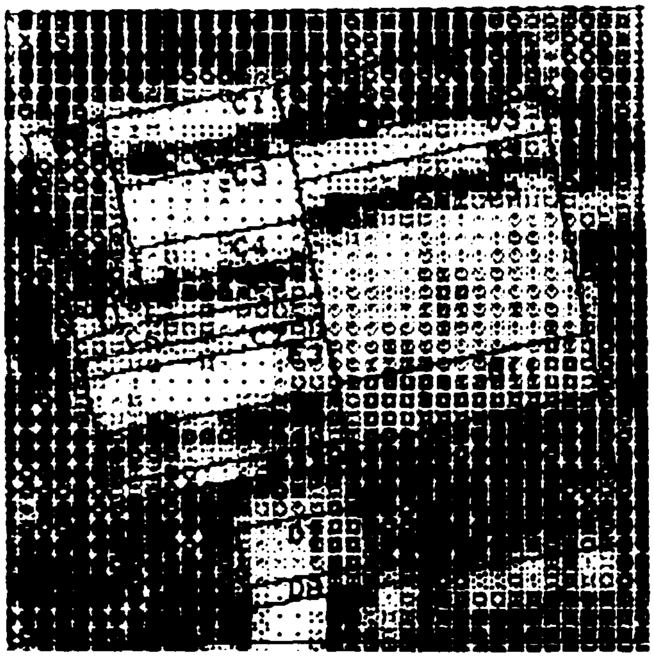


FIGURE 9a

AFTER SHIFTING- ASMA

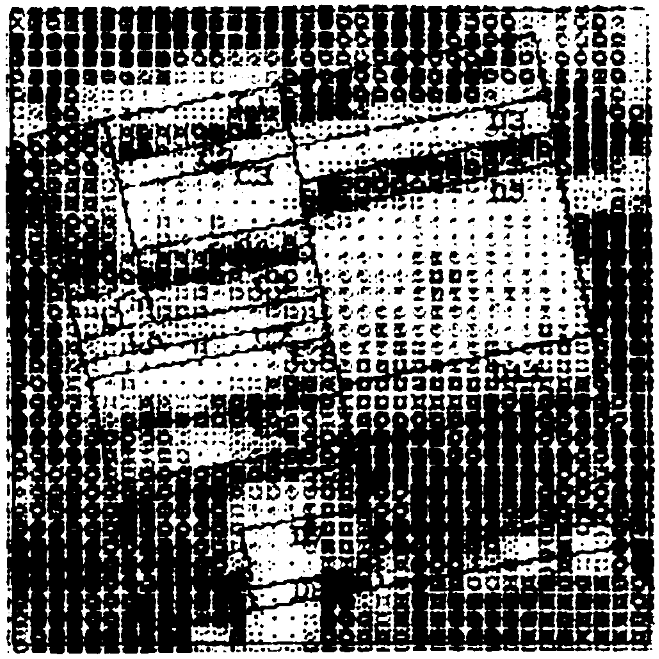


FIGURE 9b

AFTER SHIFTING (USDA)

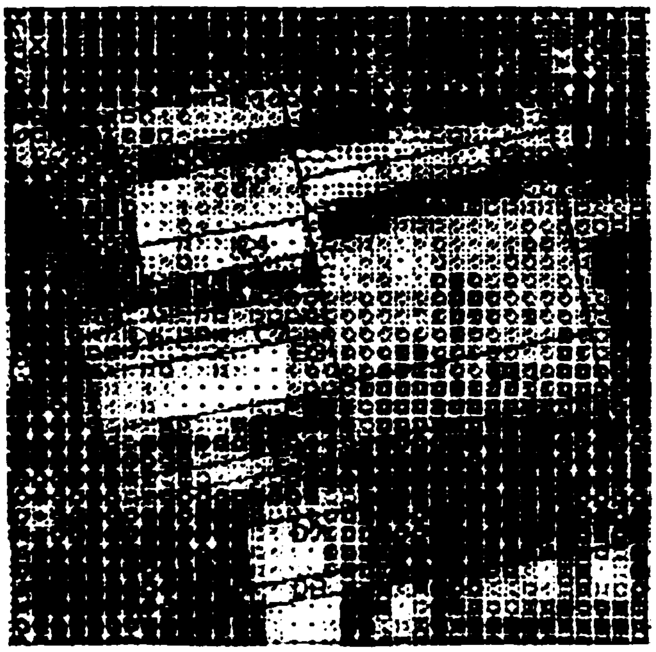


FIGURE 9c

Figure 9. Example of a Confusion Segment

ORIGINAL REGISTRATION - USDA

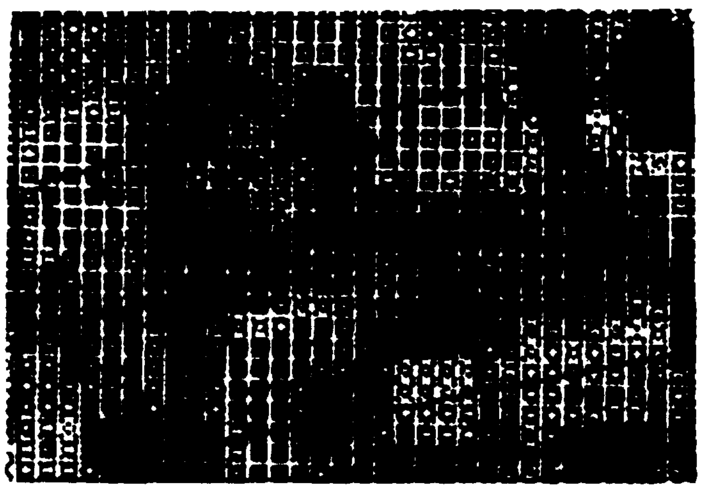


FIGURE 10a

AFTER SHIFTING (USDA) ASMA

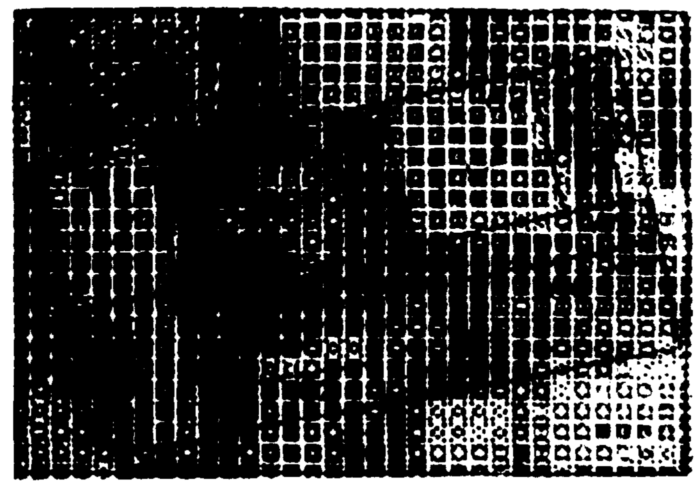


FIGURE 10b

Figure 10. Matching Segment Resulting in Same Shift as USDA/SRS

ORIGINAL REGISTRATION - USDA

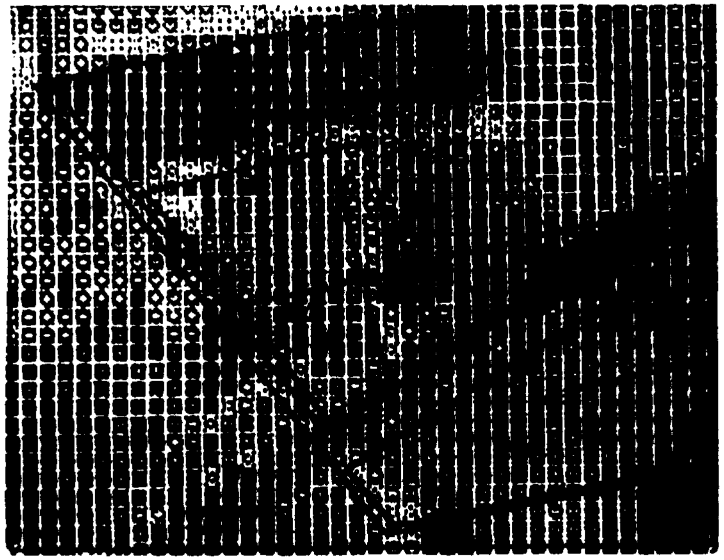


FIGURE 11a

AFTER SHIFTING- ASMA

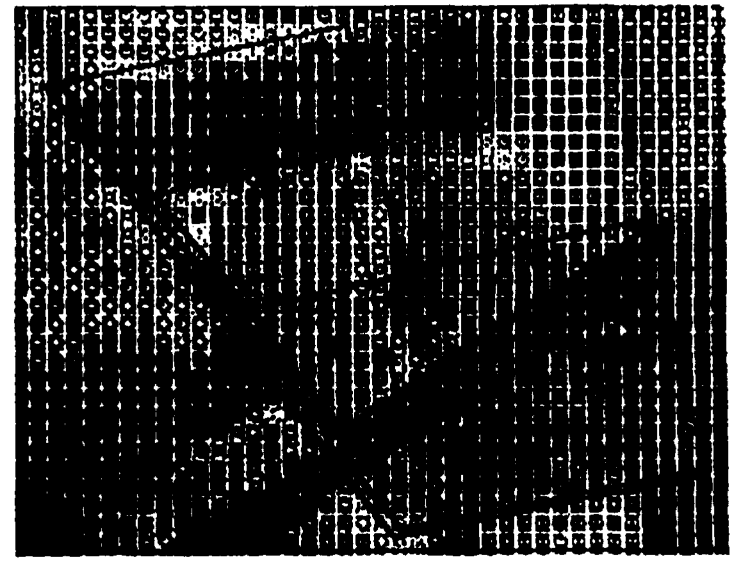


FIGURE 11b

AFTER SHIFTING - USDA

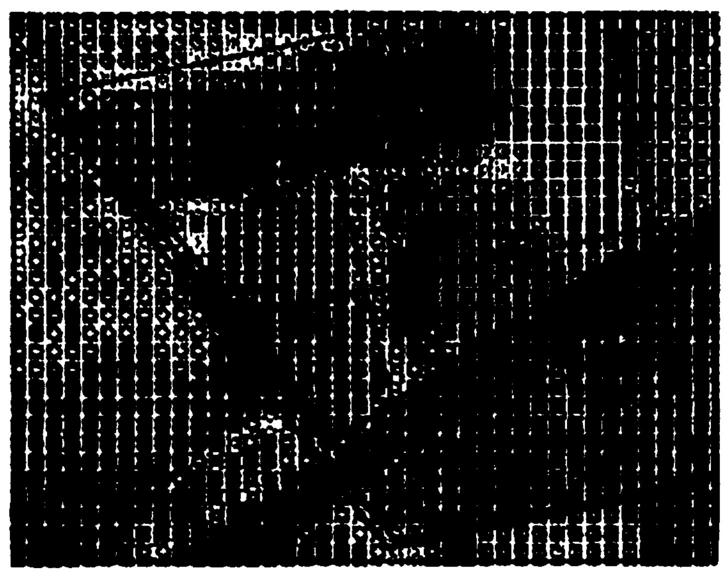


FIGURE 11c

Figure 11. Segment Shift in Which ASMA is Quarter Pixel Off

segments, the acceptance test is well established. When the number of segments is small the acceptance test is weak since there are not enough segments to construct a good confidence interval. In this case, the user may want to shift those few segments manually. The overall results are within the half pixel accuracy requirement and the algorithm is thus recommended for use with scenes with large samples of segments.

4. CONCLUDING REMARKS

The segment shifting algorithm was developed on a Perkin-Elmer 3242 32-bit minicomputer. The CPU time is listed in Table 4.1 for the six data sets tested.

COMPUTER RUN TIMES

Scene		No. of Segments	CPU Time HR: MIN: SEC
Kansas	(1)	20	0:25.26
	(2)	39	0:25.52
Missouri	(1)	9	0:4.05
	(2)	8	0:3.30
	(3)	29	0:18.20
	(4)	16	0:7.30

Table 4.1

The ASMA program has been put in the USDA/SRS EDITOR System (OZGA etal 1977). An initial USDA/SRS evaluation of the algorithm was performed on the Kansas (2) scene with 39 segments. As far as actual results, there were some minor differences in three or four of the 36 segments actually shifted. Segment 7150 resulted in a shift of -1.5 rows and -1.0 columns after ASMA was run through EDITOR. This result is for the confusion segment discussed in section 3.2, Figures 9 a, b, c. It is not certain why the result is different, particularly for this segment, but differences in machine roundoff may account for part of the problem. The rest of the segments matched exactly except for 2 which were half a pixel off.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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APPENDIX A

ASMA ERROR ANALYSIS RESULTS

KANSAS (1) ERROR ANALYSIS FOR ASMA

SEGMENT	AVG. MANUAL SHIFT		ASMA SHIFT		DIFFERENCES	
	ROW	COLUMN	ROW	COLUMN	ROW	COLUMN
20	1.75	-1.75	3.00	-1.50	-1.25	-0.25
105	1.00	1.75	1.00	1.00	0.	0.75
117	1.00	1.50	1.50	1.00	-0.50	0.50
186	3.00	-1.00	3.00	-0.50	0.	-0.50
6050	2.00	0.	2.00	1.00	0.	-1.00
6122	3.50	-2.50	3.50	-1.50	0.	-1.00
6135	2.00	0.25	2.50	0.50	-0.50	-0.25
6199	2.25	-0.25	2.50	-0.50	-0.25	0.25
6365	1.25	0.	1.00	0.	0.25	0.
7054	2.00	0.	2.50	0.50	-0.50	-0.50
7211	2.00	-1.25	2.00	-0.50	0.	-0.75
8072	1.00	-1.75	0.50	-1.50	0.50	-0.25
8168	2.00	0.25	2.50	0.50	-0.50	-0.25
8223	1.50	-1.25	1.50	-1.50	0.	0.25
8282	1.50	0.25	1.50	1.00	0.	-0.75
9003	2.25	-0.75	2.50	-0.50	-0.25	-0.25
9294	3.00	-2.25	3.50	-1.50	-0.50	-0.75
9295	3.00	-3.00	3.00	-2.50	0.	-0.50
AVERAGES						
	2.000	-0.653	2.194	-0.361	-0.194	-0.292

RMS ERRORS EXPRESSED IN METERS

ROW RMS = 18.812 COL RMS = 30.089 TOT RMS = 35.486

KANSAS (2) ERROR ANALYSIS FOR ASMA

SEGMENT	AVG. MANUAL SHIFT		ASMA SHIFT		DIFFERENCES	
	ROW	COLUMN	ROW	COLUMN	ROW	COLUMN
3200	-0.50	-1.50	-0.50	-1.50	0.	0.
1160	-2.50	2.50	-2.50	2.50	0.	0.
1920	0.50	-1.00	0.	-1.50	0.50	0.50
1930	-0.50	-2.50	-0.50	-2.50	0.	0.
2470	-1.50	-0.50	-2.00	-0.50	0.50	0.
3590	-0.50	-1.50	-0.50	-1.50	0.	0.
1133	-1.50	-1.50	-1.00	-1.50	-0.50	0.
1135	-1.50	-2.25	-1.50	-1.50	0.	-0.75
1319	-1.00	-0.50	0.	0.	-1.00	-0.50
7065	-0.50	-1.50	-0.50	-2.00	0.	0.50
7066	-0.50	-2.50	-0.50	-2.50	0.	0.
7150	-2.00	-1.50	-0.50	-0.50	-1.50	-1.00
7151	-1.50	-2.00	-1.00	-2.50	-0.50	0.50
7152	-1.00	-2.00	-1.50	-2.00	0.50	0.
7153	-1.00	-1.50	-1.00	-1.00	0.	-0.50
7276	0.	-1.00	0.	-1.00	0.	0.
7329	-1.00	-2.50	0.	-2.00	-1.00	-0.50
7379	-1.00	-1.50	-1.00	-0.50	0.	-1.00
8082	-0.50	-2.50	0.	-2.00	-0.50	-0.50
8083	-1.00	-2.50	-1.00	-2.50	0.	0.
8229	0.	-0.50	0.	-0.50	0.	0.
8389	-0.50	-2.50	-0.50	-2.00	0.	-0.50
8431	0.50	-1.00	0.50	-1.00	0.	0.
9098	-1.50	0.50	-1.00	1.00	-0.50	-0.50
9099	-1.00	-2.50	-0.50	-2.00	-0.50	-0.50
9180	-1.00	-2.50	-0.50	-2.50	-0.50	0.
9241	0.	-1.00	0.	-1.00	0.	0.
9299	-1.50	-1.50	-1.50	-1.50	0.	0.
9348	-1.00	-2.00	-1.00	-1.50	0.	-0.50
9349	0.	0.	0.	-0.50	0.	0.50

AVERAGES

-0.833	-1.425	-0.667	-1.267	-0.167	-0.158

RMS ERRORS EXPRESED IN METERS

ROW RMS = 19.621   COL RMS = 21.754   TOT RMS = 29.295

MISSOURI (1) ERROR ANALYSIS FOR ASMA

SEGMENT	AVG. MANUAL SHIFT		ASMA SHIFT		DIFFERENCES	
	ROW	COLUMN	ROW	COLUMN	ROW	COLUMN
6334	-2.50	-2.50	-2.00	-2.50	-0.50	0.
6335	-2.25	-2.75	-2.00	-2.50	-0.25	-0.25
6338	-2.50	-3.00	-2.00	-2.50	-0.50	-0.50
6352	-3.50	-2.00	-3.50	-2.00	0.	0.
6353	-2.25	-1.25	-2.50	-1.00	0.25	-0.25
6354	-2.50	-1.38	-2.50	-1.00	0.	-0.38
AVERAGES						
	-2.583	-2.147	-2.417	-1.917	-0.167	-0.230

RMS ERRORS EXPRESSED IN METERS

ROW RMS = 18.164 COL RMS = 15.154 TOT RMS = 23.655

MISSOURI (2) ERROR ANALYSIS FOR ASMA

SEGMENT	AVG. MANUAL SHIFT		ASMA SHIFT		DIFFERENCES	
	ROW	COLUMN	ROW	COLUMN	ROW	COLUMN
6337	-0.50	-3.00	0.	-2.50	-0.50	-0.50
6339	-0.50	-2.50	-1.00	-2.00	0.50	-0.50
6340	-0.25	-2.75	0.	-2.50	-0.25	-0.25
6343	-0.25	-3.75	-0.50	-3.50	0.25	-0.25
6344	-0.50	-2.00	0.	-3.00	-0.50	1.00
6345	-1.00	-2.50	-0.50	-2.00	-0.50	-0.50
AVERAGES						
	-0.500	-2.750	-0.333	-2.583	-0.167	-0.167

RMS ERRORS EXPRESSED IN METERS

ROW RMS = 25.754 COL RMS = 33.419 TOT RMS = 42.192

MISSOURI (3) ERROR ANALYSIS FOR ASMA

SEGMENT	AVG. MANUAL SHIFT		ASMA SHIFT		DIFFERENCES	
	ROW	COLUMN	ROW	COLUMN	ROW	COLUMN
6316	-1.75	-3.50	-2.00	-3.00	0.25	-0.50
6317	-1.88	-3.63	-2.00	-3.50	0.12	-0.13
6326	-0.75	-3.50	0.	-3.00	-0.75	-0.50
6356	-1.75	-1.50	-1.50	-1.00	-0.25	-0.50
6357	-1.50	-1.25	-1.50	-1.50	0.	0.25
6358	-1.50	-2.25	-2.00	-1.50	0.50	-0.75
6359	-1.00	-1.50	-1.00	-1.50	0.	0.
6360	-1.25	-1.25	-1.00	-0.50	-0.25	-0.75
6361	-1.50	-2.75	-2.00	-2.50	0.50	-0.25
6362	-1.50	-3.75	-1.50	-3.00	0.	-0.75
6363	-1.00	-3.50	-0.50	-3.00	-0.50	-0.50
6365	-0.50	-2.75	0.	-3.00	-0.50	0.25
6380	1.25	-4.25	2.00	-3.50	-0.75	-0.75
6446	-2.00	-2.00	-2.00	-2.00	0.	0.
6450	-1.75	-2.75	-1.00	-3.00	-0.75	0.25
6450	-2.25	-3.50	-2.00	-3.50	-0.25	0.
AVERAGES						
	-1.289	-2.727	-1.125	-2.438	-0.164	-0.289

RMS ERRORS EXPRESSED IN METERS

ROW RMS = 17.208 COL RMS = 24.735 TOT RMS = 30.132

MISSOURI (4) ERROR ANALYSIS FOR ASMA

SEGMENT	AVG. MANUAL SHIFT		ASMA SHIFT		DIFFERENCES	
	ROW	COLUMN	ROW	COLUMN	ROW	COLUMN
6318	0.50	-2.25	1.00	-1.50	-0.50	-0.75
6328	-0.50	-1.75	-0.50	-1.00	0.	-0.75
6329	-1.00	-1.25	-1.00	-0.50	0.	-0.75
6331	-1.50	-0.25	-1.50	0.	0.	-0.25
6332	-1.00	-0.75	-0.50	0.	-0.50	-0.75
6346	-2.00	-1.00	-1.50	-1.00	-0.50	0.
6347	-2.00	-1.50	-2.00	-1.00	0.	-0.50
6348	-2.50	-0.75	-2.50	-0.50	0.	-0.25
6349	-1.50	-0.25	-1.50	0.	0.	-0.25
6350	-1.50	-0.25	-1.50	0.	0.	-0.25
6351	-1.50	-0.50	-1.50	0.	0.	-0.50
6414	0.	-2.50	0.50	-2.00	-0.50	-0.50

AVERAGES

-1.208	-1.083	-1.042	-0.625	-0.167	-0.458

RMS ERRORS EXPRESSED IN METERS

ROW RMS = 16.378   COL RMS = 28.240   TOT RMS = 32.645

APPENDIX B

MANUAL SHIFTING RESULTS

MANUAL SHIFTING STATISTICS FOR MISSOURI DATA

MISSOURI (1)

MANUAL SHIFTING STATISTICS

SEGMENT	ROW 1	COL 1	ROW 2	COL 2	AVG. ROW	AVG. COL	ROW DIF	COL DIF
6333	-1.00	-3.50	-1.00	-3.50	-1.00	-3.50	0.	0.
6334	-2.50	-2.50	-2.50	-2.50	-2.50	-2.50	0.	0.
6335	-2.00	-3.00	-2.50	-2.50	-2.25	-2.75	0.50	-0.50
6336	-2.50	-3.50	-2.50	-4.00	-2.50	-3.75	0.	0.50
6338	-2.50	-3.00	-2.50	-3.00	-2.50	-3.00	0.	0.
6352	-3.50	-2.00	-3.50	-2.00	-3.50	-2.00	0.	0.
6353	-2.00	-1.00	-2.50	-1.50	-2.25	-1.25	0.50	0.50
6354	-2.50	-1.25	-2.50	-1.50	-2.50	-1.38	0.	0.25
6355	-2.50	-1.50	-2.00	-1.00	-2.25	-1.25	-0.50	-0.50
AVERAGE VALUES								
	-2.33	-2.36	-2.39	-2.39	-2.36	-2.38		

AVERAGE ROW DIFFERENCE = 0.06   AVERAGE COLUMN DIFFERENCE = 0.03

REPEATABILITY VARIANCES AND RMS

ROW REP. = 0.0469   COL REP. = 0.0664
ROW RMS = 0.2165   COL RMS = 0.2577 IN PIXELS

MISSOURI (2)

MANUAL SHIFTING STATISTICS

SEGMENT	ROW 1	COL 1	ROW 2	COL 2	AVG. ROW	AVG. COL	ROW DIF	COL DIF
6337	-0.50	-3.00	-0.50	-3.00	-0.50	-3.00	0.	0.
6339	-0.50	-2.50	-0.50	-2.50	-0.50	-2.50	0.	0.
6340	0.	-3.00	-0.50	-2.50	-0.25	-2.75	0.50	-0.50
6342	0.	-3.00	0.	-3.50	0.	-3.25	0.	0.50
6343	0.	-3.50	-0.50	-4.00	-0.25	-3.75	0.50	0.50
6344	-0.50	-2.00	-0.50	-2.00	-0.50	-2.00	0.	0.
6345	-1.00	-2.50	-1.00	-2.50	-1.00	-2.50	0.	0.
AVERAGE VALUES								
	-0.36	-2.79	-0.50	-2.86	-0.43	-2.82		

AVERAGE ROW DIFFERENCE = 0.14   AVERAGE COLUMN DIFFERENCE = 0.07

REPEATABILITY VARIANCES AND RMS

ROW REP. = 0.0417   COL REP. = 0.0625
ROW RMS = 0.2041   COL RMS = 0.2500 IN PIXELS

MISSOURI (3)

MANUAL SHIFTING STATISTICS

SEGMENT	ROW 1	COL 1	ROW 2	COL 2	AVG. ROW	AVG. COL	ROW DIF	COL DIF
6161	1.00	-3.50	1.00	-4.00	1.00	-3.75	0.	0.50
6164	0.75	-4.00	0.50	-4.00	0.63	-4.00	0.25	0.
6316	-2.00	-3.50	-1.50	-3.50	-1.75	-3.50	-0.50	0.
6317	-1.25	-3.75	-2.50	-3.50	-1.88	-3.63	1.25	-0.25
6319	-2.50	-4.25	-2.00	-4.00	-2.25	-4.13	-0.50	-0.25
6326	-1.00	-3.50	-0.50	-3.50	-0.75	-3.50	-0.50	0.
6356	-2.00	-1.50	-1.50	-1.50	-1.75	-1.50	-0.50	0.
6357	-2.00	-1.50	-1.00	-1.00	-1.50	-1.25	-1.00	-0.50
6358	-1.50	-2.00	-1.50	-2.50	-1.50	-2.25	0.	0.50
6359	-1.00	-1.50	-1.00	-1.50	-1.00	-1.50	0.	0.
6360	-1.00	-1.50	-1.50	-1.00	-1.25	-1.25	0.50	-0.50
6361	-1.50	-3.00	-1.50	-2.50	-1.50	-2.75	0.	-0.50
6362	-1.50	-4.00	-1.50	-3.50	-1.50	-3.75	0.	-0.50
6363	-1.50	-3.50	-0.50	-3.50	-1.00	-3.50	-1.00	0.
6364	-1.50	-2.00	-1.00	-2.50	-1.25	-2.25	-0.50	0.50
6365	-0.50	-3.00	-0.50	-2.50	-0.50	-2.75	0.	-0.50
6379	-1.50	-1.50	-1.50	-1.50	-1.50	-1.50	0.	0.
6380	1.00	-4.50	1.50	-4.00	1.25	-4.25	-0.50	-0.50
6413	-2.00	-1.50	-1.00	-2.00	-1.50	-1.75	-1.00	0.50
6432	-1.50	-1.50	0.	-0.50	-0.75	-1.00	-1.50	-1.00
6446	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	0.	0.
6450	-2.00	-2.50	-1.50	-3.00	-1.75	-2.75	-0.50	0.50
6450	-2.50	-3.50	-2.00	-3.50	-2.25	-3.50	-0.50	0.

AVERAGE VALUES

-1.28	-2.74	-1.00	-2.65	-1.14	-2.70

AVERAGE ROW DIFFERENCE = -0.28   AVERAGE COLUMN DIFFERENCE = -0.09

REPEATABILITY VARIANCES AND RMS

ROW REP. = 0.2074   COL REP. = 0.0881
ROW RMS = 0.4554   COL RMS = 0.2968 IN PIXELS

MISSOURI (4)

MANUAL SHIFTING STATISTICS

SEGMENT	ROW 1	COL 1	ROW 2	COL 2	AVG. ROW	AVG. COL	ROW DIF	COL DIF
6305	-0.50	-2.00	0.	-2.00	-0.25	-2.00	-0.50	0.
6318	0.50	-2.50	0.50	-2.00	0.50	-2.25	0.	-0.50
6320	0.	-3.00	-0.50	-3.00	-0.25	-3.00	0.50	0.
6327	-1.00	-2.00	-1.00	-1.00	-1.00	-1.50	0.	-1.00
6328	-0.50	-1.50	-0.50	-2.00	-0.50	-1.75	0.	0.50
6329	-1.00	-1.50	-1.00	-1.00	-1.00	-1.25	0.	-0.50
6330	-0.50	0.	-0.50	0.	-0.50	0.	0.	0.
6331	-1.50	-0.50	-1.50	0.	-1.50	-0.25	0.	-0.50
6332	-1.00	-1.00	-1.00	-0.50	-1.00	-0.75	0.	-0.50
6346	-2.00	-1.00	-2.00	-1.00	-2.00	-1.00	0.	0.
6347	-2.00	-1.50	-2.00	-1.50	-2.00	-1.50	0.	0.
6348	-2.50	-1.00	-2.50	-0.50	-2.50	-0.75	0.	-0.50
6349	-1.50	0.	-1.50	-0.50	-1.50	-0.25	0.	0.50
6350	-1.50	0.	-1.50	-0.50	-1.50	-0.25	0.	0.50
6351	-1.50	-0.50	-1.50	-0.50	-1.50	-0.50	0.	0.
6414	0.	-2.50	0.	-2.50	0.	-2.50	0.	0.

AVERAGE VALUES

	-1.03	-1.28	-1.03	-1.16	-1.03	-1.22

AVERAGE ROW DIFFERENCE = 0.0   AVERAGE COLUMN DIFFERENCE = -0.13

REPEATABILITY VARIANCES AND RMS

ROW REP. = 0.0167   COL REP. = 0.1000
ROW RMS = 0.1291   COL RMS = 0.3162 IN PIXELS