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AN ALGORITHM FOR AUTOMATING THE REGISTRATION OF USDA SEGMENT GROUND DATA TO LANDSAT MSS DATA

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16. ABSTRACT Under the AgRISTARS Domestic Crops and Land Cover Project, a scene-to-map registration task was necessary to improve the registration of June Enumerative Survey and Land Cover Survey ground data with Landsat MSS data. An algorithm has been developed to automatically register the ground data to Landsat data to eliminate the manual "segment shifting" technique now in use by the U.S. Department of Agriculture, Statistical Reporting Service (SRS). The algorithm is referred to as the Automatic Segment Matching Algorithm (ASMA). The ASMA uses control points or the annotation record of a P-format Landsat computer-compatible tape as the initial registration to relate latitude and longitude to Landsat rows and columns. It searches a given area of Landsat data with a 2x2 sliding window and computes gradient values for bands 5 and 7 to match the segment boundaries. The gradient values are held in memory during the shifting (or matching) process. The reconstructed segment array, containing ones (1's) for boundaries and zeros elsewhere are computer compared to the Landsat array and the best match computed. Initial testing of the ASMA indicates that it has good potential for replacing the manual technique. Plans include testing and refinement of the algorithm in the Sacramento Valley, California study during FY1982.					
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AN ALGORITHM FOR AUTOMATING THE REGISTRATION OF USDA SEGMENT GROUND DATA TO LANDSAT MSS DATA

I. SUMMARY

An algorithm for automating the segment ground data shifting process used by U.S. Department of Agriculture (USDA)/Statistical Reporting Service (SRS) has been developed. The segment shifting process is the procedure used in the registration of SRS segment ground data to Landsat MSS data. The algorithm is referred to as the Automated Segment Matching Algorithm (ASMA). The initial evaluation of this algorithm indicates that it has good potential for replacing most of the manual segment shifting procedure presently used by the SRS. The algorithm will be tested in a Sacramento Valley, California, study during FY1982.

II. INTRODUCTION

The first part of the scene-to-map registration task under the AgRISTARS Domestic Crops and Land Cover (DCLC) project was to evaluate the registration accuracy of the P-format Landsat data. This was done and reported in AgRISTARS Report DC-Y1-04069 (NSTL/ERL-197), April 1981 (reference 1).

The second part of this task was to develop an algorithm that would automate the process of segment shifting. This process, given an initial or gross scene-to-map registration, translates the SRS segment outline plus or minus x columns of Landsat data and plus or minus y rows of Landsat data to locate a better fit of segment ground data to Landsat MSS data.

III. SRS SEGMENT

The SRS segment (reference 2) is an area of land which has been randomly selected by USDA as a sample unit in some land use stratum. It is usually divided into several ownership tracts, and further subdivided into fields. Each field represents an area on the ground to be considered homogeneous with respect to ground cover. The boundaries of these areas do not overlap. There is no restriction (other than computer file storage space limitations) on the complexity of the field boundaries.

Trained enumerators visit each segment and record the crop or ground cover and size of the various fields. Segment boundaries and locations are marked on aerial photos and USGS topographic quadrangle maps.

Segment digitization is the process of converting segments from fields drawn on aerial photographs or topographic maps to a file of coordinates in a geographic coordinate system. Location of points on the photos or maps are measured by hand using a data tablet digitizer, in conjunction with interactive EDITOR software subsystems, and assembled into a convenient computer-readable data structure. This data structure contains all the topological, geographic, and naming information needed to completely reconstruct the segment.

IV. SRS PROCEDURE FOR MANUAL SEGMENT SHIFTING

The initial registration of the segment to the Landsat data is performed using a least-squares fitting procedure based on control points. Control points are features on both the map and the Landsat scene whose coordinate pairs are used to compute the transformation coefficients.

Once the registration has been completed, the segment can be plotted (using the EDITOR software) in the Landsat coordinate system. An example of such a plot is shown in Figure 1.

Corresponding areas of the Landsat data are also plotted using a raster plotter and showing each Landsat pixel as a pattern of dots. Examples of this type of plot are shown in Figures 2 and 3. These raster plots are produced to the same scale as the segment plot, and represent larger areas than the digitized segment. This allows for the shifting of the segment to find a better local fit. The numbers at the top and bottom of the plots in Figures 1, 2, and 3 represent Landsat columns. The numbers at the sides represent Landsat rows.

The process of obtaining the shift numbers is begun by selecting either the plot of the channel 2 data (Figure 2) or the plot of the channel 4 data (Figure 3). The one chosen should best represent the patterns that appear in the plot of the segment (Figure 1).

The plots are usually placed on a back-lighted table and the corners of the rectangle that circumscribe the segment (Figure 1) are aligned with the four X's in the raster plot (Figure 2 or Figure 3). For this particular segment, the X's are where rows 180 and 215 intersect columns 780 and 814. The initial registration is achieved once the corners of the segment rectangle overlay the four X's on the raster plot of the Landsat.

If the segment plot can be moved up or down, or to the right or left (or both) so that it better matches the pattern in the Landsat plot, then the shift numbers for the better fit are recorded in terms of \pm columns and \pm rows. For the segment in Figure 1, the shift numbers were determined to be + 1 row and 0 columns, using this manual shift method.

V. AUTOMATED SEGMENT MATCHING ALGORITHM (ASMA)

A. Initial Registration

As in the case of the manual shifting method, the automated algorithm requires an initial registration as a starting point about which to search for a better fit. As presently coded, the algorithm can use either the registration that is already available in the annotation record of a P-format CCT or the USDA/SRS initial registration referred to earlier.

The P-format registration information is given in terms of HOTINE tick marks (reference 1). The SRS initial registration is usually based on a global cubic polynomial determined by control points chosen by SRS.

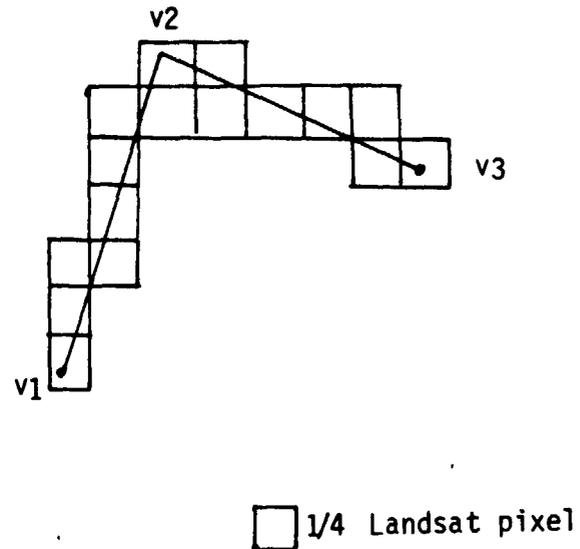
B. Segment Reconstruction

The segment description information resulting from the digitizing process along with the initial registration can be used to reconstruct the segment in the Landsat coordinate system. The file used during the segment digitizing process contains the digitizer plate coordinates and mapping coefficients that relate the plate coordinates to latitude and longitude. The initial registration can then be used to relate the latitude and longitude to Landsat rows and columns.

The segment is reconstructed at half Landsat row and column intervals by rounding the computed Landsat coordinates to the nearest half row and half column. The segment is reconstructed as an array where 1's represent boundary points, 0's represent points outside the segment, and USDA/SRS assigned field numbers represent each field within the segment. For the technique used in this algorithm, boundary points are defined as points

that touch any line connecting two vertices.

For example, according to the figure at right, v_1 , v_2 , and v_3 are typical vertices from the SRS segment file, which are converted to Landsat rows and columns and are computed to within 1/2 Landsat row and 1/2 Landsat column. Any 1/4 Landsat pixel that touches the line connecting two vertices is assigned a boundary value of 1.



For the boundary matching part of the algorithm, the field numbers are ignored. The field numbers are used for the second stage test of within field dispersion described in Section VI.B, Second Stage.

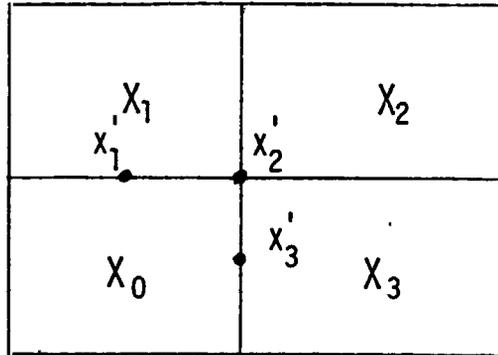
An example of the segment boundaries reconstructed by this technique is given in Figure 4. However, in practice, the algorithm does not write the reconstructed segment to a device; the algorithm builds the segment as an array and holds it in memory during the shifting process.

C. Preparation of Landsat Data-Edge Enhancement

The search window in the Landsat data is determined by the initial registration; that is, the segment vertices can be converted to Landsat row and column numbers. From these, the maximum row and column and the minimum row and column for the segment can be determined. The

search window in the Landsat data is taken to be 10 rows and 10 columns more than each maximum and 10 rows and 10 columns less than each minimum.

For the given search window, as a 2 by 2 sliding window is moved through the data, the following gradient values based on the diagram and equations below are computed.



$$x_1' = \frac{|X_0 - X_1|}{2}$$

$$x_2' = \sqrt{\left(\frac{X_0 - X_2}{2}\right)^2 + \left(\frac{X_1 - X_3}{2}\right)^2}, \text{ and}$$

$$x_3' = \frac{|X_0 - X_3|}{2}$$

These values are computed in bands 5 and 7 and added to determine the total gradient value for each point. The maximum total value is set to 10 because the intent of the edge enhancement is to use relative values to determine if a pixel is different from its neighbor. As will be explained later, the algorithm uses these relative values by summing them when they

coincide with 1's (boundaries) in the reconstructed segment. It was determined by earlier work that if gradient values are allowed to exceed a saturation value, then the algorithm will fail.

The Multispectral Scanner of Landsat can sense big differences in radiometric values between certain fields, whereas the segment data (ground truth) show that the fields within a segment are different but does not imply the degree of spectral difference. Therefore, if the goal of the algorithm is to match the field patterns in the segment with patterns in the Landsat data, the edges between two fields that are spectrally different cannot be weighted more than the edges between other fields.

After each X_i' ($i = 1,2,3$) is computed for a 2 by 2 window, the window is moved one column to the right and the process is repeated. After all columns are covered for the two rows, the window is moved down one row and the process is repeated for the next two rows. This process continues until the larger search window has been covered.

The output values of the sliding window occur at Landsat half rows and half columns and the resulting output array initially has 'holes' where no output values were determined. These holes are filled by averaging the eight (five at the file edges) neighboring values.

Figure 5 shows an example of an output array resulting from the edge enhancement process. The array is actually held in memory during the shifting process and is not written to a device. It is shown in Figure 5 for example only. Because the output array represents half rows and half columns, the row and column numbers are double those of the original Landsat row and column.

D. Matching Process

The reconstructed segment array, containing 1's for boundaries and 0's elsewhere (field numbers are also taken to be 0 for this part of the algorithm) is referenced to the edge array (containing gradient values 0-10) by the initial registration. The edge array is multiplied by the segment array and the results are summed. The segment array is then shifted in half column and half row increments computing the sum for each shift. The flow of the algorithm is illustrated in Figure 6.

Table 1 shows the standardized variables for these sums. The standardized variable is derived using the following equation:
$$\frac{\text{Sum} - \text{Mean}}{\text{Standard Deviation}}$$

The negative variables, i.e., those sums that were less than the mean of the 441 sums, were printed as zero's because they represent minimum matching between the segment pattern and the Landsat data. The largest sum represents the shift position with the most highly defined edges in terms of the segment boundaries. This shift position is taken as the best match in the preliminary (first) stage.

The results shown in Table 1 are for segment 305, which was used as the example in the manual shifting procedure described earlier. The algorithm found the best match to be at a shift of +0.5 rows and 0 columns. This compares to +1 row and 0 columns determined using the manual shifting procedure.

VI. RESULTS

A. First Stage

The algorithm has been evaluated initially by comparing its shift numbers for 30 segments with the shift numbers derived from the same 30

segments using the manual shifting technique (Table 2). Landsat 2 data from scene 21980-16264 (Kansas) were used for this evaluation. The segments were digitized from 1:24,000 scale USGS quadrangle sheets.

The manual shifting was performed by two different SRS personnel working independently. Both the algorithm and the SRS personnel used the SRS initial registration as a starting point in the shifting process.

Of the 30 segments used for this evaluation, 20 were June Enumerative Survey (JES) segments (as described in Section I) and ten were Land Cover Survey (LCS) segments. Fields in the LCS segments were grouped more according to land use rather than plant species. For example, fields of corn, hay, and soybeans within an LCS segment were all grouped into one field and called cropland, whereas, if these fields occurred in a JES segment they would be individually labeled as corn, hay, and soybeans. Therefore, it was anticipated that the correlation between the spectral patterns recorded by Landsat and the field boundaries as described in LCS segments would be low. The results of this evaluation (Table 2) show this to be true. The results also show that LCS segments are more difficult to match using the manual shifting method as well. This is demonstrated by the larger discrepancies in the shift numbers for the LCS segments between person A and person B (Table 2).

However, the information gained by attempting to match both JES segments and LCS segments will be important in training the algorithm as to when it cannot match the Landsat with the segments based on boundary information alone or when the boundary match is questionable.

The results of the automatic segment shifting process shown in Table 2 (First Stage) seem promising when compared to the shift numbers deter-

mined by the manual shifting procedure. However, for future purposes, some method is required to determine the reliability of shift numbers, independent of comparing them with the manual shift numbers. The algorithm shift numbers in Table 2 (First Stage) are based solely on the maximum sum (as described in Section VI.B) within the shift window.

A possible procedure for determining reliability could be based on the standardized values that are determined during the shifting process, as shown in the example in Table 1. Given that the Landsat data do contain homogeneous patterns for the search window area, the greater the standardized variable, the more reliable the shift number. In the case of nonhomogeneous areas, the standardized variables would be low because no one pattern would stand out above the others.

Thus, a cut-off point or threshold must be chosen to delineate reliable shift numbers (based on the standardized variables) from questionable and unreliable ones. For this reason the shift information obtained from the attempts to match the LCS segments (Table 2) proved most helpful. Using the standardized variable for each maximum sum for each of the 30 segments (given in Table 2), a distribution graph was constructed (Figure 7). The graph shows the standardized values of the 30 segments and indicates whether or not the segments were matched. A segment was considered matched if it was within ± 1 column and ± 1 row of either person A or person B in Table 2.

Based on the distribution in Figure 7, it appears that if a standardized value is above 3.5 or 3.6, the shift numbers corresponding to that value are reliable. Therefore, the cut-off point was taken to be 3.6 for follow-on investigations. The graph in Figure 7 also illustrates

that there is a range of standardized values for a group of segments whose shift numbers are questionable. Eight of the segments within this range were matched and ten were not. The lowest standardized value within the matched group was 2.5. A determination of the lower limit of this questionable group had to be made. It was decided that a segment whose corresponding standardized value was 2.0 or less would be flagged by the algorithm as impossible to match by this procedure. By requiring a maximum sum that was more than 2 standard deviations above the mean of the 441 shift sums at least some pattern correlation between the segment and Landsat data was required before proceeding to a second-stage test of within-field dispersion.

B. Second Stage

Within-field dispersion is being investigated as a possible test to use on the group of segments with questionable shift numbers. Within-field dispersion, as computed by this algorithm, is the sum of the variances of all fields greater than 19 points (1/4 pixels) within a segment. The variances are computed on the result of the edge enhanced data described in Section V.C, Preparation of Landsat Data-Edge Enhancement.

The variances for all fields are summed to obtain the within-field dispersion (WFD) number. The WFD numbers are computed for all shifts within the search area for which the standardized value is greater than 2.0. (As described earlier, if any standardized value is 3.6 or greater, then the shift numbers are considered reliable and the WFD number is not computed).

The WFD numbers are used in an attempt to match the segments in the group where the shift numbers are questionable and the segments do not match (Figure 7). For the 30 segments used in the evaluation, 10 segments

fall into this category. However, because there are 18 segments with questionable shift numbers, the second stage test was run on all 18.

The results of the second stage test of within-field dispersion are shown in Table 2. Of the ten segments within the questionable category that were not matched, 4 (117, 186, 8282, and 8384) were matched using the second stage test of WFD. Of the 8 segments in the questionable category that were matched, the WFD test mismatched 2 (9294 and 421).

In order for the algorithm to determine which segments were matched in the questionable set, the 12 reliable shift numbers were used to compute means and standard deviations for row and column shifts. The mean shift for the rows was 2.42 with a standard deviation of .85; the mean shift for the columns was -.71 with a standard deviation of 1.34. Therefore, any row shift in the range of .5 to 4.0 would be within 2 standard deviations (rounded to the nearest half row) of the mean row shift and likewise, any column shift in the range of -3.5 to 2.0 would be within 2 standard deviations (rounded to the nearest half column) of the mean column shift. Using these criteria to determine which segments were matched, the algorithm would have matched all the JES segments except one (9294). If the two standard deviation criteria was applied before the second stage test of within field dispersion, then all JES segments would have been matched.

The fact that many of the land cover segments could not be matched by the algorithm is not alarming. As stated earlier, many of these segments are based more on land use rather than plant species and represent factors not necessarily sensed by the Landsat MSS. More important is the fact that the algorithm should be able to determine which segments it cannot match.

VII. FOLLOW-ON TESTING

For follow-on testing, the algorithm will use the procedures and tests described in this report. That is, given a set of segment data and the corresponding Landsat MSS data, the algorithm will determine the set of all shift numbers based on the corresponding standardized values. The set of reliable shift numbers (those whose corresponding standardized values are 3.6 or above) will be used to determine which shift numbers of the questionable set (those whose standardized values are between 2.0 and 3.6) are incorrect. The criteria used will be the two-standard-deviation test described earlier. Any segment whose shift numbers are meaningless (those whose standardized values are less than 2.0) will be flagged by the algorithm as impossible to match by this procedure.

For those segments whose shift numbers are in the questionable group and those which failed the two-standard-deviation test, the within-field dispersion number test will be used to determine a new set of shift numbers which must in turn pass the two-standard-deviation test.

The final output of the algorithm will be the list of segments and the corresponding shift numbers for those that were matched. Also, the output will indicate the stage of the algorithm in which each segment was matched and identify those segments which were not matched. This algorithm is scheduled to be tested in the Sacramento Valley, California study during FY1982.

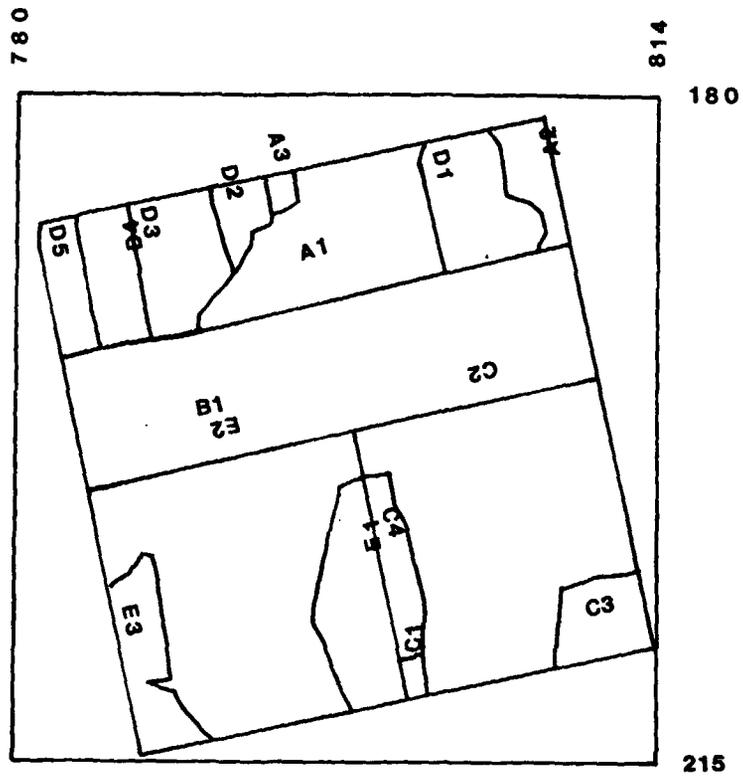


Figure 1. Plot of Digitized USDA/SRS Kansas Segment 305



Figure 2. Plot of Channel 2 (Band 5) Landsat MSS Data for Area Containing Segment 305

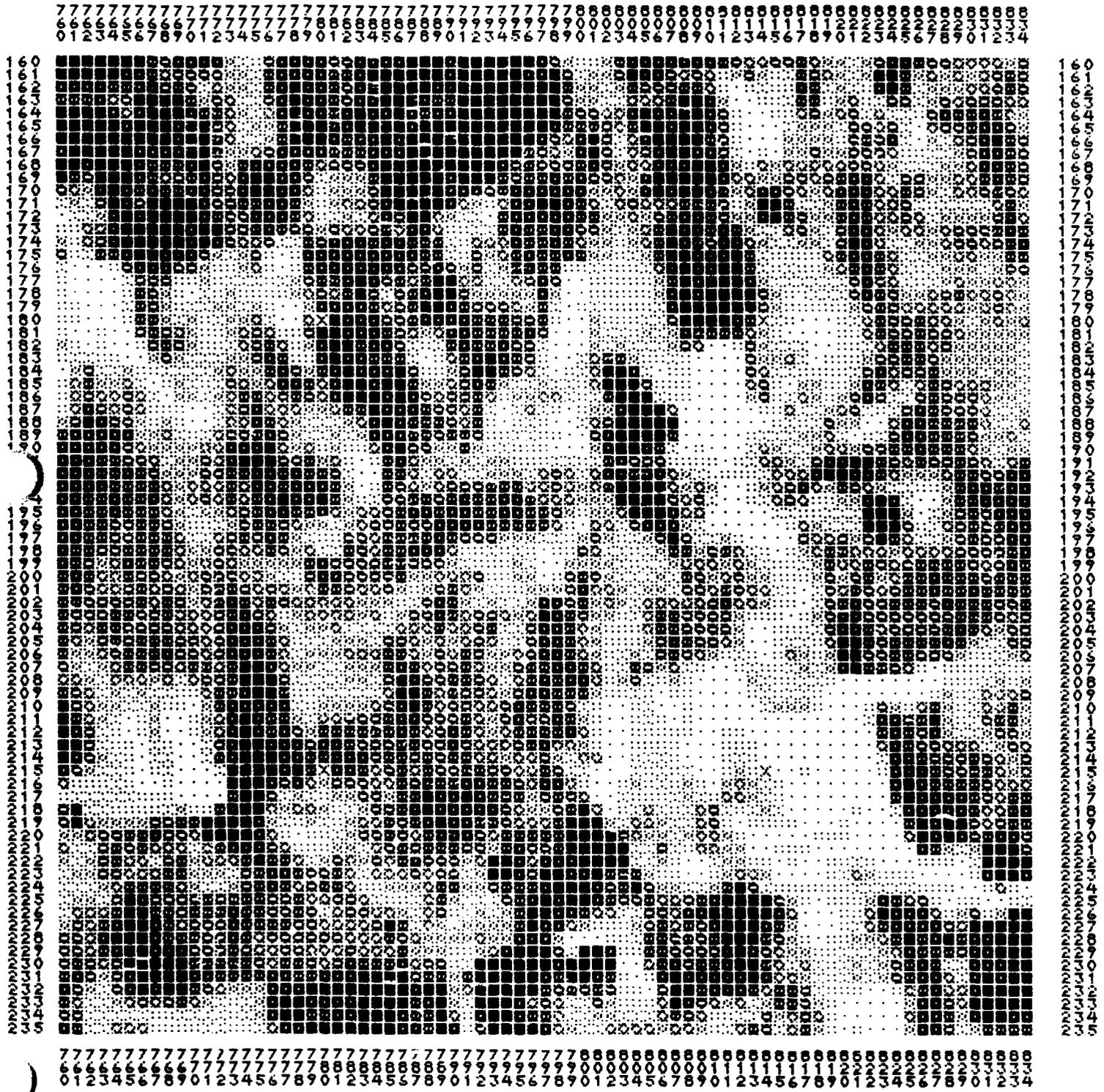


Figure 3. Plot of Channel 4 (Band 7) Landsat MSS Data for Area Containing Segment 305

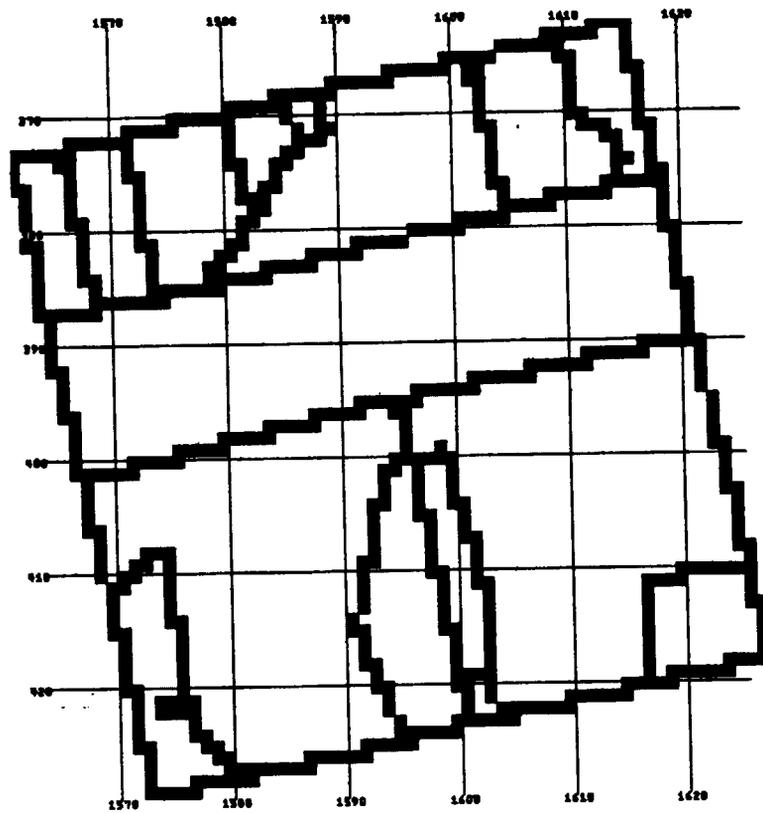


Figure 4. Plot of Segment 305 Based on Algorithm Reconstruction



Figure 5. Plot of Edge-Enhanced Landsat MSS Data

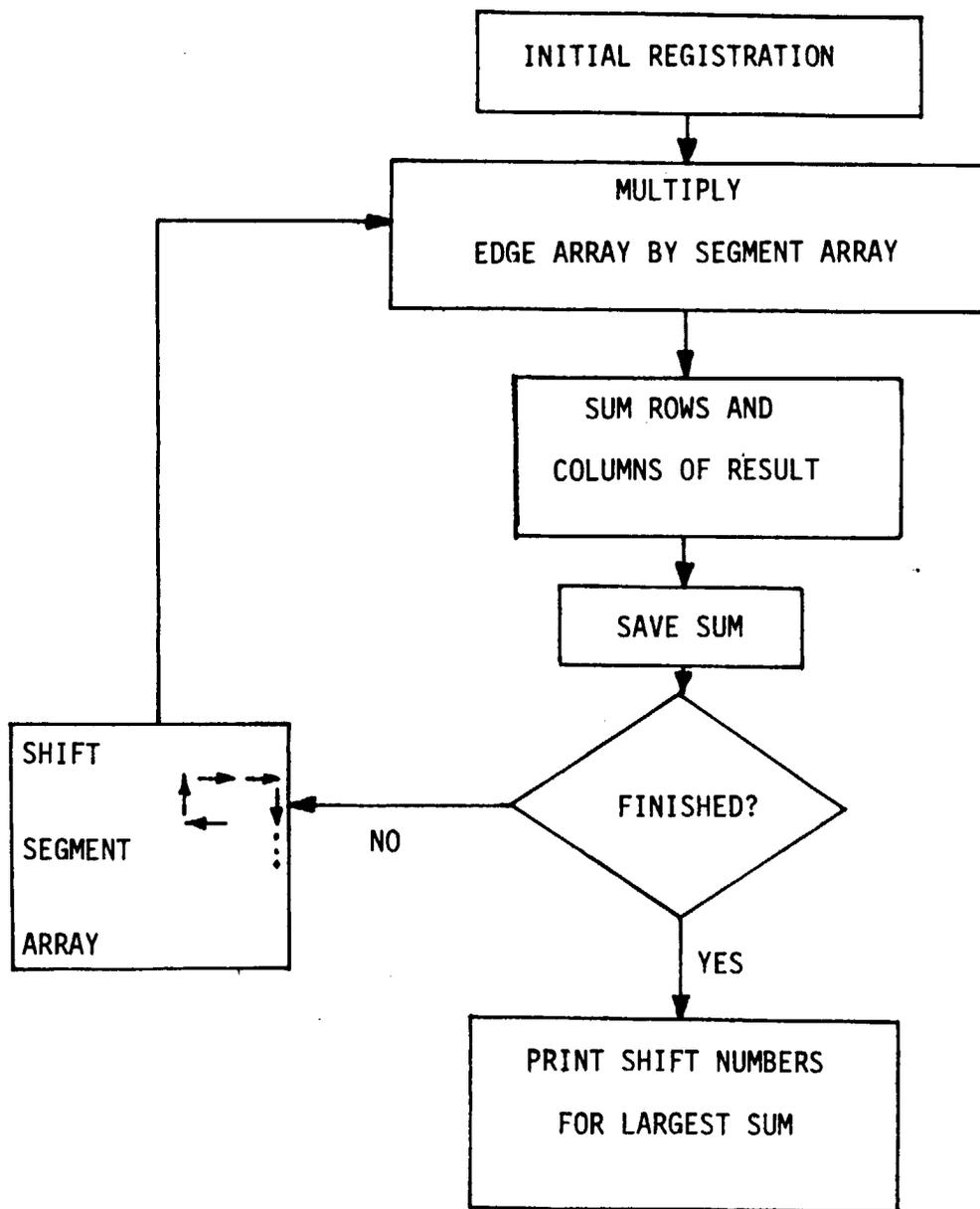


Figure 6. Flow chart for Segment matching Algorithm-first stage test for matching patterns

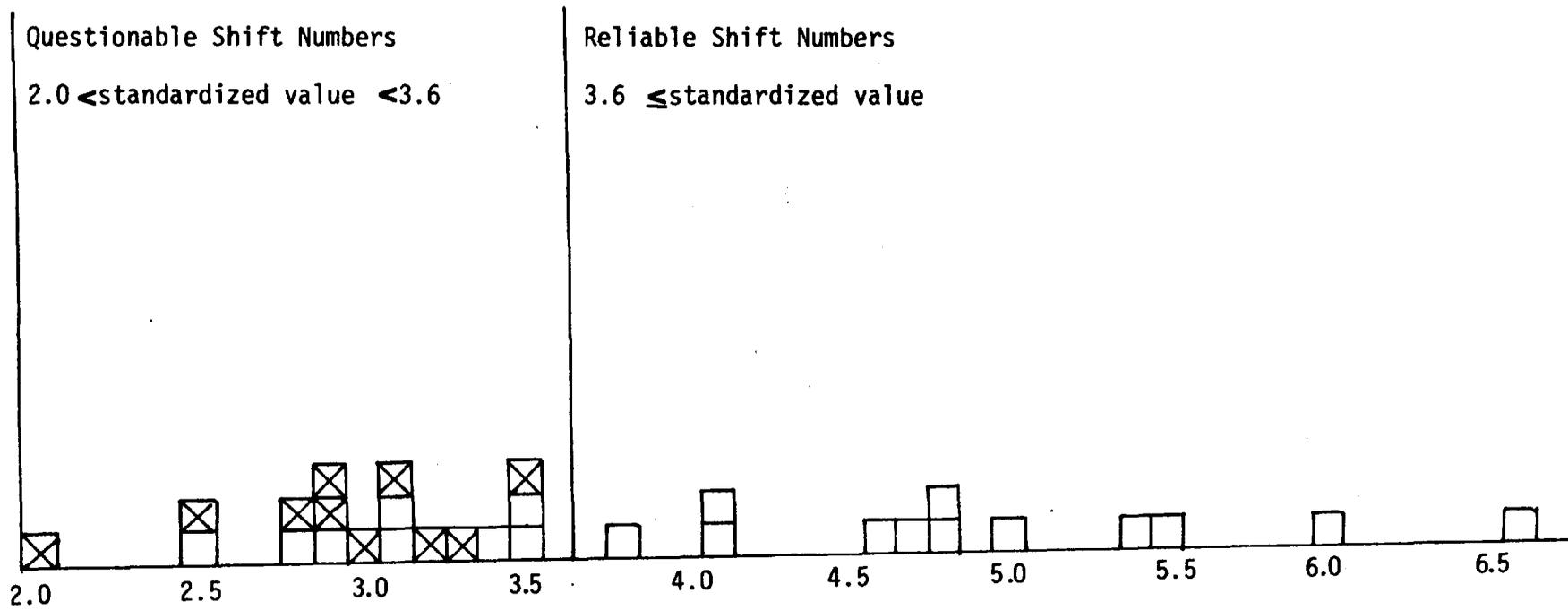


Figure 7. Standardized values for the 30 Segments vs Segment Matching Results

□ matched

⊠ not matched

Landsat Half Columns

	-20	-19	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
-20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.2	0.5	1.0	0.6	0.7	0.5
-19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.5	1.2	1.1	1.1	1.0
-18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.4	1.0	1.7	1.4	1.5	1.1
-17	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.5	0.6	1.4	1.7	1.3	1.2	1.2
-16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.3	0.3	0.7	1.1	1.6	1.2	0.9
-15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.4	0.9	1.3	1.6	1.5	0.7
-14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.9	0.8	1.4	1.5	0.5
-13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.0	0.2	0.6	0.5	1.2	1.7	0.8
-12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.2	0.5	0.9	0.4	1.0	1.5	0.4
-11	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.3	0.2	0.1	0.1	0.0	0.3	1.2	1.1	0.4
-10	0.	0.	0.	0.	0.5	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.	0.	0.1	0.6	1.1	0.1
-9	0.	0.	0.	0.	0.4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.3	1.1	0.6
-8	0.	0.	0.	0.	0.2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	1.6	0.9
-7	0.	0.	0.	0.	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.5	1.6	1.2
-6	0.	0.	0.	0.	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.2	0.3	0.6	0.0	0.0	0.4	1.7
-5	0.	0.	0.	0.	0.1	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.4	0.4	0.2	0.1	0.7	1.9
-4	0.	0.	0.	0.	0.1	0.	0.	0.	0.	0.	0.	0.	0.	0.2	0.6	1.0	1.1	0.9	1.2	2.1
-3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.3	0.8	0.8	1.2	1.2	1.4	2.2	3.6
-2	0.	0.	0.	0.	0.4	0.5	0.2	0.	0.	0.	0.	0.	0.2	0.5	0.9	1.2	1.2	1.1	2.1	3.3
-1	0.	0.	0.	0.1	0.3	0.7	0.4	0.	0.	0.	0.0	0.0	0.	0.2	0.6	0.9	0.7	1.0	2.0	3.5
0	0.	0.	0.1	0.3	0.5	0.4	0.5	0.	0.	0.	0.	0.	0.	0.1	0.8	0.7	0.7	0.6	2.0	3.2
1	0.	0.2	0.1	0.6	0.5	0.4	0.5	0.	0.	0.	0.	0.	0.	0.0	0.4	0.6	1.0	1.2	2.4	3.7
2	0.	0.	0.1	0.6	0.4	0.2	0.6	0.	0.	0.	0.	0.	0.	0.2	0.6	0.9	0.9	1.2	0.9	1.8
3	0.	0.	0.	0.3	0.3	0.3	0.7	0.	0.	0.	0.	0.	0.	0.3	0.4	0.0	0.2	0.5	0.7	1.5
4	0.	0.1	0.2	0.6	0.9	0.8	1.3	0.2	0.	0.	0.	0.	0.	0.	0.0	0.1	0.4	0.1	0.7	1.3
5	0.	0.3	0.5	0.5	0.5	0.2	0.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.3	1.0
6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.2	0.2
7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.
8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.
9	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.
10	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.
11	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

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Landsat Half Rows

Table 1. Segment 305 Shift Sums Expressed as Standardized Variables $[(\text{Sum}-\text{Mean})/\text{Standard Deviation}]$ Where Negative Variables are Printed as 0's.

Table 1. Continued

Landsat Half Columns

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
-20	0.5	0.	0.	0.1	0.6	0.6	0.2	0.3	1.0	1.3	1.1	0.6	0.5	0.6	0.6	0.3	0.1	0.6	0.7	1.0	0.6
-19	0.9	0.4	0.3	0.4	0.7	0.9	0.2	0.2	0.7	1.2	1.0	0.7	0.5	0.7	0.8	0.6	0.0	0.2	0.5	0.9	0.8
-18	1.0	0.4	0.1	0.	0.5	0.7	0.2	0.	0.6	1.0	1.1	0.8	0.7	0.9	1.0	0.3	0.1	0.2	0.9	1.1	0.9
-17	1.1	0.6	0.2	0.	0.4	0.8	0.4	0.1	0.7	1.1	1.1	1.2	1.0	1.5	1.4	0.9	0.4	0.4	0.8	0.9	0.6
-16	1.0	0.3	0.0	0.	0.1	0.4	0.5	0.3	1.2	1.3	1.8	1.9	1.7	1.6	1.5	0.7	0.5	0.3	1.0	0.7	0.3
-15	0.7	0.4	0.2	0.	0.2	0.5	0.6	0.7	1.2	1.2	1.6	2.0	1.5	1.6	1.3	0.9	0.5	0.3	0.4	0.1	0.
-14	0.5	0.3	0.5	0.	0.3	0.4	0.7	0.6	1.2	0.8	1.8	2.2	1.5	1.1	1.0	0.5	0.1	0.	0.	0.	0.
-13	0.5	0.5	0.3	0.	0.	0.2	0.5	0.7	0.8	0.4	1.1	1.6	0.8	0.5	0.5	0.6	0.3	0.	0.	0.	0.
-12	0.2	0.2	0.4	0.	0.	0.	0.2	0.	0.2	0.	0.8	1.2	0.8	0.5	0.8	0.5	0.5	0.	0.	0.	0.
-11	0.1	0.3	0.	0.	0.	0.	0.1	0.2	0.3	0.2	0.8	1.2	1.0	0.6	0.7	0.6	0.6	0.	0.	0.	0.1
-10	0.	0.	0.	0.	0.	0.	0.2	0.0	0.4	0.4	1.0	1.1	1.3	0.6	0.8	0.7	0.8	0.	0.2	0.	0.7
-9	0.2	0.3	0.2	0.2	0.	0.	0.5	0.4	0.6	0.3	0.6	1.1	1.2	0.8	0.8	0.9	0.9	0.5	0.5	0.7	1.3
-8	0.7	0.5	0.7	0.6	0.4	0.1	0.7	0.2	0.5	0.4	0.8	1.2	1.7	1.1	1.1	1.1	1.3	1.1	1.1	1.4	2.0
-7	0.9	0.5	0.6	0.9	0.6	0.6	1.1	0.8	0.8	0.9	1.1	1.4	1.7	1.5	1.5	1.8	1.7	1.7	1.2	1.3	1.6
-6	1.4	1.0	1.5	1.7	1.6	1.2	1.5	1.1	1.2	1.2	1.6	1.5	1.8	1.4	1.6	1.4	1.4	1.5	1.0	0.9	1.6
-5	2.4	1.8	2.1	2.4	2.3	2.0	1.8	1.4	1.1	1.2	1.0	0.9	1.2	1.1	1.3	1.3	1.4	1.4	0.9	1.1	1.6
-4	3.2	2.2	2.3	2.5	2.4	1.7	1.4	0.9	0.8	0.6	0.5	0.3	1.0	0.7	1.3	1.2	1.6	1.3	1.0	1.0	1.7
-3	3.6	2.5	2.6	2.3	2.0	1.5	1.1	1.0	0.7	0.4	0.3	0.2	0.7	0.6	0.9	1.3	1.8	1.5	1.0	0.9	1.5
-2	3.6	2.3	1.7	1.9	1.7	1.0	0.9	0.7	0.7	0.3	0.4	0.4	0.7	0.7	1.1	1.3	1.7	1.3	0.9	0.5	1.0
-1	4.0	2.7	1.3	1.6	1.4	1.2	0.9	1.0	1.0	0.5	0.4	0.7	0.3	0.4	0.6	0.9	1.3	1.5	0.9	0.3	0.5
0	4.5	3.3	1.8	1.6	1.6	1.2	0.9	0.6	0.7	0.2	0.0	0.4	0.1	0.6	0.7	0.6	0.9	1.3	0.9	0.	0.2
1	4.8	3.6	1.4	0.8	0.7	0.7	0.6	0.7	1.0	0.4	0.	0.2	0.	0.2	0.1	0.	0.3	0.9	1.0	0.	0.
2	4.3	3.3	1.4	0.8	0.9	0.6	0.6	0.4	1.0	0.0	0.	0.	0.	0.	0.3	0.0	0.5	0.7	0.9	0.	0.
3	3.9	3.0	1.4	0.6	0.5	0.	0.	0.	0.6	0.0	0.	0.	0.	0.	0.1	0.	0.3	0.4	0.8	0.	0.
4	2.7	2.2	1.1	0.1	0.2	0.	0.	0.	0.5	0.2	0.0	0.	0.1	0.	0.2	0.0	0.3	0.2	0.7	0.1	0.
5	1.9	1.5	1.3	0.3	0.2	0.	0.	0.	0.3	0.3	0.1	0.	0.	0.	0.	0.	0.2	0.3	0.8	0.6	0.
6	1.1	1.4	1.5	0.3	0.4	0.	0.	0.	0.	0.3	0.0	0.	0.0	0.	0.2	0.0	0.2	0.4	1.0	0.9	0.2
7	0.8	1.3	1.6	0.6	0.2	0.	0.	0.	0.	0.4	0.1	0.	0.1	0.	0.2	0.4	0.6	0.9	1.2	0.9	0.1
8	0.6	1.1	1.9	1.2	0.7	0.	0.	0.	0.	0.2	0.1	0.	0.4	0.3	0.3	0.3	0.5	0.8	1.0	0.9	0.1
9	0.5	0.8	1.7	1.3	0.6	0.2	0.1	0.2	0.2	0.3	0.1	0.	0.1	0.3	0.	0.0	0.1	0.5	0.4	0.6	0.1
10	0.3	0.3	1.6	1.5	1.0	0.5	0.3	0.4	0.1	0.1	0.	0.	0.	0.0	0.0	0.2	0.1	0.2	0.2	0.2	0.
11	0.4	0.4	1.4	1.5	1.1	0.6	0.3	0.4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.7	0.8	0.8	0.3	0.2	0.3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.0
13	0.	0.1	0.7	1.2	1.0	0.4	0.0	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.0	0.
14	0.	0.1	0.2	0.5	0.7	0.1	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.2	0.	0.
15	0.	0.1	0.	0.5	0.5	0.2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.	0.
16	0.	0.	0.	0.4	0.7	0.1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.3	0.0	0.
17	0.	0.	0.	0.	0.2	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.	0.
18	0.	0.	0.	0.	0.3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.5	0.3	0.2
19	0.	0.	0.	0.	0.3	0.2	0.	0.	0.	0.	0.2	0.	0.	0.	0.	0.	0.	0.	0.0	0.2	0.2
20	0.	0.	0.0	0.	0.5	0.2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.1	0.2	0.2

SEGMENT SHIFTED 0.5 ROWS 0. COLS.

Table 2. Results of Segment Matching Algorithm

SEGMENT	SRS PERSON A		SRS PERSON B		FIRST STAGE ALGORITHM BOUNDARY MATCH ONLY		SECOND STAGE ALGORITHM WITHIN-FIELD DISPERSION		STANDARDIZED VALUE FOR MAXIMUM SUM
	ROW	COL	ROW	COL	ROW	COL	ROW	COL	
0020 (JES)	2.5	-1.5	1.0	-2.0	3.0	-1.5			6.0
0105 (JES)	1.0	1.5	1.0	2.0	1.0	1.0			4.8
0117 (JES)	1.0	2.0	1.0	1.0	0.5	9.0	1.5	0.5	3.3
0186 (JES)	3.0	-1.0	3.0	-1.0	4.0	-8.0	2.5	0.0	2.9
6050 (JES)	2.0	0.0	2.0	0.0	2.0	1.0	3.0	0.5	3.4
6122 (JES)	3.0	-2.5	4.0	-2.5	3.5	-1.5	3.5	-2.0	2.5
6135 (JES)	2.0	0.0	2.0	0.5	2.5	0.5			3.8
6199 (JES)	2.5	-0.5	2.0	0.0	2.5	-0.5			5.4
6365 (JES)	1.5	0.0	1.0	0.0	1.0	0.0	1.0	0.0	2.9
7054 (JES)	2.0	0.0	2.0	0.0	2.5	0.5			4.8
7211 (JES)	2.0	-1.0	2.0	-1.5	2.0	-0.5	2.0	-0.5	3.1
8072 (JES)	1.0	-2.0	1.0	-1.5	0.5	-1.5			5.5
8168 (JES)	2.0	0.5	2.0	0.0	2.5	0.5			4.1
8223 (JES)	1.5	-1.5	1.5	-1.0	1.5	-1.5	1.5	-1.5	3.5
8282 (JES)	1.0	0.0	2.0	0.5	10.0	-5.5	1.5	1.0	2.5
8384 (JES)	3.5	-2.5	3.0	-3.0	5.5	9.5	4.0	-2.0	3.0
9003 (JES)	2.5	-0.5	2.0	-1.0	2.5	-0.5			4.1
9294 (JES)	3.0	-2.5	3.0	-2.0	3.5	-1.5	2.5	5.5	3.5
9295 (JES)	3.0	-3.0	3.0	-3.0	3.0	-2.5			4.6
9343 (JES)	0.5	-2.5	1.5	-2.0	0.5	-2.0	0.5	-1.5	2.8
0420 (LCS)	3.0	-3.0	3.0	-3.0	3.5	-2.5			5.0
0421 (LCS)	3.0	-1.0	-4.0	-0.5	4.5	-1.0	7.0	0.0	3.1
5392 (LCS)	1.0	-3.0	3.0	-0.5	-3.5	-3.5	-4.5	-1.5	2.9
5395 (LCS)	1.5	-2.5	0.0	-2.5	4.5	-2.0	-3.0	-3.0	3.5
5419 (LCS)	2.5	0.0	2.5	0.0	2.5	0.5			6.6
5429 (LCS)	3.0	-3.0	3.0	-3.0	3.5	-2.5			4.6
6398 (LCS)	1.0	-2.0	1.0	-2.0	2.5	6.0	3.5	-7.5	3.2
6424 (LCS)	4.0	-3.0	4.0	-0.5	4.0	-0.5	4.5	-5.0	3.1
8404 (LCS)	1.5	-0.5	1.0	0.0	1.5	-10.0	1.0	-9.5	2.8
9415 (LCS)	2.0	-2.5	2.0	-0.5	-10.0	7.5	-10.0	7.5	2.0

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