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AN ANALYSIS OF LANDSAT MSS SCENE-TO-SCENE REGISTRATION ACCURACY

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An Analysis of Landsat MSS Scene-to-Scene Registration Accuracy

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National Aeronautics and Space Administration
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Measurements of scene-to-scene registration accuracy were made for 12 registrations done by ERL and for 8 registrations done by SRS. Comparisons were made for the eight common areas.

The results indicate that the ERL method is significantly more accurate in five of the eight comparisons. The differences between the two methods are not significant in the other three cases. There are two possible reasons for the differences. First, the ERL model is a piecewise linear model and the EDITOR model is a cubic polynomial model. Second, the ERL program resamples using bilinear interpolation while the EDITOR software uses a nearest neighbor resampling. This study did not indicate how much of the difference is attributable to each factor.

The average of all merged scene error values for ERL was 31.6 meters and the average for the eight common areas was 32.6 meters. The average of the eight merged scene error values for SRS was 40.1 meters.

17. KEY WORDS
Landsat
ELAS
EDITOR
Registration
Control Points

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# INTRODUCTION

# LANDSAT DATA

# ACCURACY ASSESSMENT METHODOLOGY

# STATISTICAL MODEL

# RESULTS AND CONCLUSIONS
AN ANALYSIS OF LANDSAT MSS SCENE-TO-SCENE REGISTRATION ACCURACY

I. INTRODUCTION

This paper describes efforts by NASA's National Space Technology Laboratories (NSTL), Earth Resources Laboratory (ERL) and USDA's Statistical Reporting Service (SRS) to analyze the accuracy of scene-to-scene registration of Landsat Multispectral Scanner (MSS) data. Twelve areas, representing four major types of land cover categories, were selected for this study. Landsat MSS data were merged by both ERL and SRS. ERL used the Earth Resources Laboratory Applications Software (ELAS) system to perform the registration, while SRS used the EDITOR software system.

The specific objectives of this study were:
1. To determine the registration accuracies of the data sets merged by ERL and SRS.
2. To determine whether the registration techniques used were equally well suited for the different land cover categories studied.
3. To determine whether one registration technique produced significantly better registration.
4. To determine whether a significant relationship exists between the root mean square (rms) errors of control points used in scene-to-scene registration and the accuracies determined by this study.
II. LANDSAT DATA

One of the goals of this study was to determine the suitability of the ELAS and EDITOR registration techniques for a variety of land cover categories. The general surface cover categories chosen were agriculture, rangeland, forest, and mixed. The mixed category comprises areas with both forest and agriculture.

Three test sites were selected for each of the four land cover categories, for a total of 12 test sites. Two Landsat scenes were used by ERL for each site. Table 1 lists each Landsat scene and its land use category.

To minimize tape mailing between SRS and ERL, two sites from each of the four land cover categories were registered by SRS and the merged data were mailed to ERL for comparison of the two registration techniques. The two registration techniques were compared for these eight sites.
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<th>LAND COVER CATEGORIES</th>
<th>LOCATION AND LANDSAT SCENE</th>
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<td>N. CAROLINA (17/36)</td>
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<td></td>
<td>MISSISSIPPI (23/39)</td>
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<tr>
<td>MIXED (FOREST AND AGRICULTURE)</td>
<td>S. CAROLINA (18/36)</td>
</tr>
<tr>
<td></td>
<td>IDAHO (46/27)</td>
</tr>
</tbody>
</table>

* (XX/XX) = PATH/ROW NUMBERS.
III. ACCURACY ASSESSMENT METHODOLOGY

For each of the test sites analyzed, the Landsat scenes were merged by ERL using the ELAS software. SRS used the EDITOR software to merge eight of the sites. The accuracy of the merged data sets was then assessed.

The accuracy assessment procedure consisted of generating gray-scale electrostatic plots of the data and selecting test points using a digitizer. In this procedure two gray-scale plots were made of two bands of the base Landsat scene for approximately 16 different subscene areas. A third plot was made of one band of the merged Landsat scene. Then, for each subscene area, all three plots were mounted on a digitizer and matching test points were selected from each plot. In the cases of Missouri, Kansas, Colorado, and Kentucky, a fourth plot was made for each subscene area of one band of the data merged by SRS. Then all four plots were mounted on the digitizer at one time. Thus, these four comparisons were made on identical points. The four remaining comparisons are based on independently selected test points.

The points selected from the two plots of two bands of the base Landsat scene were used to estimate the random effect of a human selecting the same test points in this manner. The points selected from the plots of the merged Landsat data, when compared to the test points of the base Landsat scene, measured the random human error in addition to the registration error. A statistical procedure was used to separate the two sources of error and estimate the portion attributable to misregistration by the registration software.
IV. STATISTICAL MODEL

In the model, \([(x_{b1i},y_{b1i})|1<i<n]\) represents the set of \(x\) and \(y\) coordinates of the test points \((i)\) selected from the first band of the base scene \((b_1)\), 
\([(x_{b2i},y_{b2i})|1<i<n]\) represents the set of coordinates of the test points selected from the second band of the base scene \((b_2)\), and \([(x_{mi},y_{mi})|1<i<n]\) represents the coordinates of the test points selected from the merged scene \((m)\). These constitute all the measured variables. Several formulas will be derived using the \(x\) coordinates. Similar formulas exist for the \(y\) coordinates but will not be explicitly derived.

For the purposes of this model several assumptions are made. First it is assumed that, for each \(i\),

\[x_{b1i} = x_i + \epsilon_{b1i}\]

where \(x_i\) is the true location of the test point and \(\epsilon_{b1i}\) is the error of the human selecting the points. Likewise, assume that

\[x_{b2i} = x_i + \epsilon_{b2i}\]

Further, assume that

\[x_{mi} = x_i + \epsilon_{mi} + \alpha_i\]

where \(\epsilon_{mi}\) is the human error in selecting the point and \(\alpha_i\) represents the mis-registration at that point.

In addition, assume that \(\epsilon_{b1}, \epsilon_{b2}, \epsilon_{m},\) and \(\alpha\) are all independent random variables, normally distributed, with mean 0 and variances \(\sigma_{xb1}^2, \sigma_{xb2}^2, \sigma_{xm}^2,\) and \(\sigma_\alpha^2\). It is assumed that \(\sigma_{xb1}, \sigma_{xb2},\) and \(\sigma_{xm}\) are all equal to \(\sigma_{xh}\), which will represent the human error in selecting points.
Then consider the differences between $x_{b1i}$ and $x_{b2i}$. In particular,

$$
\sum_{i=1}^{n} \frac{(x_{b1i} - x_{b2i})^2}{n}
$$

which can be simplified as follows:

$$
\sum_{i=1}^{n} \frac{(x_i + \varepsilon_{b1i} - x_i - \varepsilon_{b2i})^2}{n}
$$

The assumption of independence yields

$$
\sum_{i=1}^{n} \frac{\varepsilon_{b1i}^2}{n} + \sum_{i=1}^{n} \frac{\varepsilon_{b2i}^2}{n} = \sigma_{xb1}^2 + \sigma_{xb2}^2 = 2\sigma_{xh}^2
$$

Thus we get a simple formula for estimating the human error component:

$$
\sigma_{xh}^2 = \frac{1}{2n} \sum_{i=1}^{n} \frac{(x_{b1i} - x_{b2i})^2}{n}
$$

Now consider the difference between $x_{mi}$ and the average of $x_{b1i}$ and $x_{b2i}$:

$$
\sum_{i=1}^{n} \frac{(x_{mi} - \frac{x_{b1i} + x_{b2i}}{2})^2}{n}
$$

$$
= \frac{1}{n} \sum_{i=1}^{n} \left( x_i + \varepsilon_{mi} + \alpha_i - \frac{x_i + \varepsilon_{b1i} + x_i + \varepsilon_{b2i}}{2} \right)^2
$$

$$
= \frac{1}{n} \sum_{i=1}^{n} \left( \varepsilon_{mi} + \alpha_i - \frac{\varepsilon_{b1i}}{2} - \frac{\varepsilon_{b2i}}{2} \right)^2
$$
The assumption of independence yields:

\[
\sum_{i=1}^{n} \frac{e_{mi}}{n}^2 + \sum_{i=1}^{n} \frac{a_i^2}{n} + \frac{1}{4} \sum_{i=1}^{n} \frac{c_{bli}}{n}^2 + \frac{1}{4} \sum_{i=1}^{n} \frac{e_{b2i}}{n}^2
\]

\[
= \sigma_{XH}^2 + \sigma_a^2 + \frac{1}{2} \sigma_{XH}^2
\]

Using formula (1) to replace \( \sigma_{XH}^2 \) we get:

\[
\sigma_a^2 = \sum_{i=1}^{n} \left( x_{mi} - \frac{x_{bli} + x_{b2i}}{2} \right)^2 - \frac{3}{4} \sum_{i=1}^{n} \frac{(x_{bli} - x_{b2i})^2}{n}
\]  

These two formulas yield values for \( \sigma_{XH} \) and \( \sigma_a \) in terms of pixels. The rms error of the control points is expressed in meters so an expression of the misregistration in meters is desirable.

\[
\sigma_x = 57 \sigma_a
\]

Similarly, a formula could be derived for \( \sigma_y \). Combining \( \sigma_x \) and \( \sigma_y \), one gets a value for the total rms error, \( \sigma_M \):

\[
\sigma_M = \sqrt{\sigma_x^2 + \sigma_y^2}
\]

A useful expression can be derived to determine the radius which contains 90\% of the data. Assuming a normal distribution, the density function is

\[
\frac{1}{2\pi \sigma_x \sigma_y} e^{-\frac{1}{2} \left( \frac{x}{\sigma_x}^2 + \left( \frac{y}{\sigma_y} \right)^2 \right)}
\]

This can be approximated as

\[
\frac{1}{2\pi \sigma^2} e^{-\left( \frac{x^2 + y^2}{2\sigma^2} \right)}, \text{ where } \sigma = \frac{\sigma_x + \sigma_y}{2}
\]
Integrating over a circle of radius $R$ gives

$$Q = \int_0^{2\pi} \int_0^R \frac{1}{2\pi\sigma^2} e^{-\left(\frac{x^2 + y^2}{2\sigma^2}\right)} \, dx \, dy$$

$$= \int_0^{2\pi} \int_0^R \frac{1}{2\pi\sigma^2} e^{-\frac{r^2}{2\sigma^2}} \, r \, dr \, d\theta$$

$$= 1 - e^{\frac{-R^2}{2\sigma^2}}.$$

Solving this for $R$ gives

$$R = \sigma \sqrt{2 \ln\left(\frac{1}{1-Q}\right)}$$

or

$$R = \left(\frac{\sigma_x + \sigma_y}{2}\right) \sqrt{2 \ln\left(\frac{1}{1-Q}\right)}.$$

For $Q = 0.9$ the radius becomes

$$R_{90} = \left(\frac{\sigma_x + \sigma_y}{2}\right) 2.146.$$
V. RESULTS AND CONCLUSIONS

The results of this study are listed in Table 2. For the 12 sites tested, the ELAS algorithm had an average merged scene error ($\sigma_M$) of 31.6 meters. In the eight test sites with comparable values for the EDITOR algorithm, the average of ELAS $\sigma_M$ values was 32.6, while the average of EDITOR values was 40.1. Further, each $\sigma_M$ value is lower for the ELAS data sets. Thus an F-test for significance was done to test whether the ELAS values were significantly smaller. The results are listed in Table 2.

An analysis was done to determine if any relationship existed between rms errors and $\sigma_M$ values. However, this failed to yield any substantial results. The Spearman's rank correlation coefficient between these two variables was 0.159, a value too low for significance.

The last analysis was to see if a significant difference existed for $\sigma_X$ values among the four general categories. However, in all four categories there was a significant difference between some pair of $\sigma_M$ values. Thus differences among categories are less than differences within categories.

In conclusion, one may state that the ERL scene-to-scene registration is significantly better in five of the eight comparisons. There are two possible reasons for the differences. First, the ERL model is a piecewise linear model and the EDITOR model is a cubic polynomial model. Second, the ERL program resamples using bilinear interpolation while the EDITOR software uses a nearest neighbor resampling. This study did not indicate how much of the difference is attributable to each factor.
### TABLE 2. TEST RESULTS

<table>
<thead>
<tr>
<th>Land Cover Test Areas</th>
<th>ERL Control Point RMS Error ($\sigma_{XH}$)</th>
<th>Number of Test Points</th>
<th>Model RMS Error ($\tilde{\sigma}_H$)</th>
<th>F-Test Results* ($\tilde{\sigma}_H$) ERL Vs. SRS</th>
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* $H_0: \sigma^2_{SRS} \leq \sigma^2_{ERL}$, $\alpha = 0.10$

$H_A: \sigma^2_{SRS} > \sigma^2_{ERL}$