Quality of Production Orthophotos

Assessment of accuracy and image quality of orthophotos produced by different orthophoto instrumentation employed by different organizations is presented.

INTRODUCTION

The increasing demand for photomaps and orthophoto products has made it commercially feasible for a significant number of mapping organizations to acquire orthophoto equipment and offer photomapping services to their clients.

The buyer of orthophoto equipment makes his selection from among instruments differing greatly in price, convenience of operation, scale range, speed and optional extras, but the one thing that the manufacturers of all these instruments agree on, is that their equipment can produce excellent orthophotos.

The buyer of a map generally wants a competitive price from a reliable firm using good equipment. Notwithstanding the manufacturer's claims, if he is buying a photomap, he tends to wonder if it makes a significant difference what type of orthophoto equipment his contractor uses.

Since the Topographical Survey acts as a contracting agent and inspector for the mapping requirements of many Federal departments, some overall evaluation of the orthophoto equipment in use in Canada was required to serve as a guide in planning photomapping projects. The object of this paper is to report on the results of this evaluation.

The Relationship of Production Orthophotos to Contract Mapping

Among the many factors affecting the quality of a photomap a few were selected that seemed most relevant to planning photomap projects. These were:

- The accuracy of production orthophotos from a number or different sources.
- The capability of orthophoto instruments to handle a variety of terrain types.
- The image quality, when the products are evaluated at an enlarged photo scale.

There are, of course, many other factors which affect the quality of an orthophoto such as the adjustment and calibration of the instrument, the operator's skill, and the choice of photographic materials and processes. These factors are generally outside the control of those purchasing a photomap product, the assumption being that a qualified contractor is using the best production methods suited to his equipment, which he keeps in good operating condition. This assumption was made when the following test data were assembled.

THE TEST PROGRAM

There are five makes of differential rectifiers in use in Canada at the present time and these can be classified according to their image-forming and scanning methods as follows:

1. Optical image transfer with sharp focus, manual scanning (Zeiss GZ-1, Jena Ortho-phot).
2. Optical image transfer with depth of field
focus, manual scanning (SFOM Ortho-
photographic Unit 693, Kelsh Orthopho-
toscope).

3. Electronic image transfer, electronic cor-
relation (Gestalt Photo Mapper).

All five instruments were used in the pro-
duction of selected orthophotos, as was the
Zeiss SEG V rectifier.

The areas selected for the evaluation were
chosen on the basis of terrain relief and came
from current photomapping projects. The
photography was taken with modern wide-
angle survey cameras (152mm focal length).

1. Low-relief area: Two adjacent stereo-
overlaps of agricultural land, photo-
graphed at a scale of 1:19 000, and hav-
ing a differential relief of less than 1% of
the flying height were used.

2. Moderate-relief area: One stereo-overlap
of moderately rolling, mixed bush, agri-
cultural and urban land was selected as
being representative of the most usual
photomap subject. The differential relief
was about 4% of the flying height and the
photo-scale was 1:38 000.

3. Mountainous terrain: Two adjacent stereo-
overlaps were chosen from a 1:50 000
photomapping project in the Yukon Ter-
ritory. The terrain can best be described
as rugged. The mountains, rising to ridges
at 1800m (6000ft.) are cut by valleys in
every direction. The valley slopes are
often 25° to 30°. The differential relief
in the 1:50 000 scale photography is
about 13% of the flying height.

A section from each of these areas is
shown in Figure 1.

One set of film diapositives was made of
each of these areas and the set was sent in
turn to each of the six organizations involved
in making the orthophotos.

The resulting orthophotos were examined
for image faults, and sections of the ortho-
photos were brought to a common, enlarged
scale for a comparison of the image quality.

The standard used for checking the ac-
curacy of the orthophotos was a stereoscopic
model formed in a Wild A-7 plotter from the
diapositives used in making the orthophotos.
The planimetric coordinates of corresponding
image points were measured in the stereo-
model and in the orthophoto. A similarity
transformation using the method of least
squares provided the RMS deviation of the
orthophoto points from the standard.

**Image Analysis and Test Results**

**The Effect of Scanning**

Orthophotos produced by plane rectification
have the best chance of coming through the
orthophoto reproduction stage with the
minimum number of acquired defects. If the
film can be kept clean and free of scratches
the image quality can be very similar to that
of an ordinary print or enlargement.

The scanning operation of differentially-
rectified orthophotos can impose a number
of defects on the imagery in addition to the
normal hazards of reproduction. These in-
clude tone matching between scans, scan
lines, blurring, duplication of imagery, and
discontinuities at scan lines.

Different instruments use slightly different
methods to overcome these potential threats
to the appearance of the product, and the
performance of all the instruments used in
this test was remarkably good. The two most
severe tests were the large areas of uniform
tone in the low-relief models and the extreme
slopes of the mountainous models.

**The Shape of the Slit**

Most strip-scanning instruments use a slit
with sloped ends (Figure 2) which provides
an area of blending exposure between ad-
joining scans. The amount of this doubly-
exposed area is usually about 5% of the total
area. The SFOM used with a slit having a
blending area of 10%, produced the most uni-
form tone over the open farmland of the low
relief models. For the strip scanners, shading
in tone across the width of the strip was
probably the most obvious indication of the
scanning, and this tended to occur at the
larger field angles where the light is pro-
jected obliquely.

**Scanning Difficulties in Mountainous Terrain**

The mathematics of image displacement
due to errors inherent in the scanning-slit
method of differential rectification have been
well documented by Ahrendl and Marsik,
but implied in the computation is a fore-
knowledge of terrain slopes and camera field
angles which is usually not available at the
planning stages of a mapping project.

Figure 3 shows the extent to which mul-
tiple images may occur on a 24° cross-slope
at a field-angle of 35°. The unrectified im-
agery in Figure 3a has been transformed
rather crudely in 3b by the use of a slit
width of 2.4mm at photo-scale. A 0.5mm
slit, the narrowest available on a slit-scanning
instrument was used to produce the imagery.
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Fig. 1. Sections from test models.

LOW RELIEF: Photo-scale 1:19,000, \( \Delta H = 0.6\% \)

MODERATE RELIEF: Photo-scale 1:38,000, \( \Delta H = 4\% \)

MOUNTAINOUS: Photo-scale 1:50,000, \( \Delta H = 13\% \)
of 3c. The patch-scanning method used in the Gestalt Photo Mapper is not subject to this type of error, as is shown in 3d.

Another type of multiple imagery shown in Figure 4 occurred on the mountainous models scanned in the SFOM with a slit which was almost as wide as it was long, and had a blending area of 42%. Marsik\textsuperscript{4} has shown that in order to avoid the effect illustrated, the width of the slit must be much smaller than its length. In this particular case the slits provided by the instrument
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30° slope scanned with a slit almost as wide as long (4 × photo-scale)

manufacturer did not change in width for the shorter-length slits. Other scanning instruments provide the user with progressively narrower slits as the slit length decreases.

Blurring of the imagery occurred on all the strip-scanning instruments when rapid upward or downward movement of the slit was required to accommodate 30° slopes. The Gestalt Photo Mapper, which is quiescent at the instant of exposure, can produce normal imagery on such a slope (Figure 5).

All the orthophotos in the mountainous terrain, including those produced by patch scanning, showed some form of image-garbling on slopes at large field angles. If imagery is sufficiently garbled it defies accuracy measurement, so only valley points and peak points were used in the accuracy assessment of these models.

THE EFFECT OF THE IMAGE FORMATION SYSTEM

The rectifier and the differential rectifiers using sharp focus or electronic imagery produce a uniform image quality throughout their range of operation. The SFOM 693 Orthophotograph Unit and the Kelsh Orthophotoscope on the other hand depend on establishing a model scale at the optimum projection distance for the lens, and performing the scanning in "Z" within the depth of field of the lens. The image quality is not uniform throughout the operational range of the instrument, as is illustrated in Figure 6, and falls off in quality more rapidly at the longer projection distances. This would seem to indicate that the best overall image quality would be obtained in these instruments if the majority of the model were at the optimum distance or slightly less.

THE EFFECT OF REPETITIVE REPRODUCTION

When a photomap finally reaches the hands of the user, the image he sees is often many generations removed from the original aerial photography and it usually looks like it.

Collins and Kalensky2 have studied the transfer of resolution in orthophotos from the negative to the orthophoto print, and Welch7 has provided an application of MTF theory to this type of multiple reproduction. These researchers have indicated the magnitude of the loss of resolution at each reproduction step.

In this test, a comparison was made of the final product from a number of different inputs after they had been through the normal series of reproduction steps involved in making a photomap. A scale of 1:10 000 repre-
senting 3.8 times photo-scale, was arbitrarily chosen as the point at which to compare imagery. Some instruments produced orthophotos directly at the required scale; others, because of instrument limitations, required an additional scaling step. The total number of reproduction steps involved in reaching the samples shown in Figure 7 were:

1. Aerial negative to diapositive.
2. Diapositive to orthonegative
3. Orthonegative to scaled positive.
4. Scaled positive to screened negative.
5. Screened negative to reproduction plate.
6. Reproduction plate to illustration.

With minor variations this is the reproduction route taken by many photomaps. The products of the six instruments shown may have varied slightly in image quality at the orthonegative stage, but this variation has been virtually lost in reproduction.

It was found that the dominant factor affecting the amount of detail and the appearance of the final reproduction was contrast. If the contrast is too high at any step, highlight detail is lost and never regained. If the contrast is too low the image lacks clarity for interpretation, and the appearance of the sheet is most unattractive.

**Planimetric Accuracy**

**Planimetric Accuracy of the Differential Rectifications**

Approximately twenty-five image points were measured in each of the orthophotos. The scale at which the measurements were made varied with the scale of the various orthophotos. The RMS deviations from the Wild A-7 model were therefore all reduced to their value at photo-scale in the preparation of Table 1.

Since it is wished to establish the common denominator of accuracy for the product, no distinction is made in this table with respect to instrument type. In fact there was no
These sections are taken from 1:10,000 orthophotos (3.8 x photo-scale) made on 6 different instruments and represent image quality after 6 reproduction steps, including screening.
Table 1. Planimetric Accuracy of Differentially Rectified Orthophotos Produced in Different Organizations

<table>
<thead>
<tr>
<th>Elevation Difference % Flying Height</th>
<th>Number Orthophotos Tested</th>
<th>RMS Deviation At Photo-scale</th>
<th>Best</th>
<th>Worst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low relief</td>
<td>0.6%</td>
<td>4</td>
<td>0.04mm</td>
<td>0.06mm</td>
</tr>
<tr>
<td>Low relief</td>
<td>0.9%</td>
<td>4</td>
<td>0.04mm</td>
<td>0.06mm</td>
</tr>
<tr>
<td>Moderate relief</td>
<td>4%</td>
<td>7</td>
<td>0.03mm</td>
<td>0.06mm</td>
</tr>
<tr>
<td>Mountainous</td>
<td>13%</td>
<td>5</td>
<td>0.06mm</td>
<td>0.12mm</td>
</tr>
<tr>
<td>Mountainous</td>
<td>12%</td>
<td>5</td>
<td>0.08mm</td>
<td>0.19mm</td>
</tr>
</tbody>
</table>

The correlation between accuracy and instrument in the complete data. One value, indicating the actual worst case in a mountainous model, is bracketed because it is substantially worse than all other cases and represents a model which was scanned with a slitwidth inappropriate to the terrain (Figure 3b).

If the RMS deviations of this table are used as the MSE (63% of the points) for the determination of the Circular Map Accuracy Standard (90% of the points), then the potential enlargement factor from photo-scale can be determined for the orthophoto products. Using a CMAS of 0.5mm means that all the low- and moderate-relief orthophotos could be enlarged about 5.5 times and still meet this accuracy for the single orthophoto. Orthophotos in mountainous terrain on the other hand, could be enlarged only 1.6 times if the same criterion is used.

Low relief:

\[0.06 \text{ (RMS)} \times 1.5174 = 0.09 \text{mm (CMAS)}\]

Enlarged 5.5 \(= 0.5 \text{mm (CMAS)}\)

Mountainous:

\[0.20 \text{ (RMS)} \times 1.5174 = 0.3 \text{mm (CMAS)}\]

Enlarged 1.6 \(= 0.5 \text{mm}\)


Displacement of Ground Points in Treed Areas

A systematic displacement in the position of ground points within treed areas can be detected in orthophotos produced by automatic electronic correlation.

Artificially-marked ground-level points were positioned in or near trees at the maximum radial distance of a model to be scanned. The locations of some of these points (numbers 4 to 10) are shown in the moderate-relief illustration of Figure 1. The measured errors at these points were not used in the similarity transformation or in the determination of the RMS value for the orthophoto. Instead, their residuals in X and Y were plotted as a vector diagram and compared with the computed correction for objects at tree-top height at the position of the points. These diagrams are shown in Figure 8.

There is a definite correlation between tree-top correction and position error of ground points in the orthophotos from the Gestalt Photo Mapper. The correlation of the imagery and the correction due to elevation will tend to occur near tree-top level in this automatic system.

A compiler operating a strip-scanner on the other hand, will tend to go through the trees at what he estimates as ground level so that he will have the slit on the ground when he comes out the other side.

The image accuracy of the photomap might be considered more correct on the correlation scan than on the manual scan since it is the tree-tops which form the bulk of the imagery. However, the implication of this effect is that artificial tie points on models to be electronically scanned should not be placed in close proximity to trees; otherwise difficulties may be encountered in matching the point to its plotted position on a manuscript.

Accuracy of Orthophotos Produced by Plane Rectifications

The use of orthophotos produced by plane rectifications is of course limited by the amount of differential relief present in the area to be photomapped. The criterion generally used (Doyle,\(^3\) Marsik\(^4\)) is that the maximum elevation difference from datum shall not cause a displacement of greater than the required CMAS when this difference occurs at the maximum radial distance in the portion of the photograph being used.

Based on this criterion, the maximum
Computed radial correction at tree-top level for a number of points located in the corner of a differentially rectified orthophoto.

Measured displacement of artificially marked ground points adjacent to the trees. The magnitude of the RMS error on all other measured points in the orthophoto is indicated by the circle.

**Fig. 8. Displacement of Ground points in treed areas.**

scale at which a rectification could be used in making a photomap in each of the test areas can be computed. The height differential is known, a CMAS of 0.5mm can be chosen, and a maximum radial distance when using the central portion of photography having 60% forward overlap and 30% lateral overlap (a maximum field angle of 30°20') can be assumed for production work. These scales are shown in Table 2.

In this study, rectifications were made for each area and these were checked for planimetric accuracy in the same manner as the differentially rectified orthophotos. From the measured MSE of the rectifications, a CMAS value at photo-scale can be computed (CMAS = 1.5174 MSE), and from this, the maximum rectification scale at which this CMAS would equal 0.5mm. These values are shown in Table 3.

A comparison of computed and potential scales in these tables shows that where the relief distribution is relatively uniform and without gullies, as was the case with the test models, the standard criterion used for determining the maximum scale for rectification is very conservative.

**Conclusions**

It was gratifying to find that the orthophoto products available from a variety of production organizations using different instrumentation were comparable in accuracy and image quality.

The accuracy of differentially-rectified orthophotos is such that image quality, rather than accuracy, would probably be the governing factor in deciding the degree of enlargement which can be usefully used for a project.

Mountainous or steeply accented terrain presents particular problems—problems which...
### Table 3. Potential Rectification Scale Based on Measured Errors

<table>
<thead>
<tr>
<th>Test Area</th>
<th>Photo-Scale</th>
<th>CMAS at Photo-Scale (Measured)</th>
<th>Enlargement Factor For CMAS = 0.5mm</th>
<th>Potential Map Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Relief</td>
<td>1:19 000</td>
<td>0.085mm</td>
<td>5.9 ×</td>
<td>1:3 200</td>
</tr>
<tr>
<td>Moderate Relief</td>
<td>1:38 000</td>
<td>0.38 mm</td>
<td>1.3 ×</td>
<td>1:29 200</td>
</tr>
<tr>
<td>Mountainous</td>
<td>1:50 000</td>
<td>2.87 mm</td>
<td>0.17 ×</td>
<td>1:295 000</td>
</tr>
</tbody>
</table>

are aggravated by the use of wide-angle lenses. Although loss of accuracy and image quality can be tolerated to a greater extent in such areas, there is a limit to the terrain ruggedness beyond which it becomes impractical to attempt orthophoto production. For example, we do not have the intention of initiating large scale photomapping of Banff National Park.

The rectifier as an orthophoto instrument should not be forgotten. If there is a more or less uniform distribution of relief in the area to be photomapped, equating the “worst case error” with the required CMAS is perhaps unnecessarily conservative. A more practical guideline might be the circular near-certainty error (99.8%) for the map.

And above and beyond all else, maintaining the image quality of a photomap through many reproduction steps remains one of the most difficult assignments of this type of mapping.

**AUTHOR'S NOTE:** the instruments used in the production of the orthophoto imagery of Figure 7 were (1) Gestalt Photo Mapper, (2) Orthophot, (3) Gigas-Zeiss GZ-1, (4) SFOM, (5) Kelsh.

### References


### Articles for Next Month

A. P. Colvocoresses and R. B. McEwan, EROS cartographic progress.

M. E. Davies, Mariner 9: primary control net.

E. E. Derényi, Orientation of continuous-strip imagery.

N. Jensen, High-speed image analysis techniques.

G. L. LaPrade, Stereoscopy—will dogma or data prevail?

C. P. Lo and F. Y. Wong, Micro-scale geomorphology features.

H. Makarian, et al., Digital correction for high-resolution images.

C. J. Reinheimer, et al., Detection of petroleum spills.