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Quality of Production Orthophotos

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

Abstract: *An overall assessment of the accuracy and image quality of orthophotos produced in different organizations using different orthophoto instrumentation has been made in order to provide a guide to the planning of photomapping projects to be done by contract. The orthophotos were found to be comparable in accuracy and image quality, but there was significant deterioration of both these items in steeply accented terrain. Image quality tends to be the limiting factor in the determination of the practical enlargement of the orthophoto.*

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 Orthophot).
2. Optical image transfer with depth of field

focus, manual scanning (SFOM Orthphotographic Unit 693, Kelsh Orthophotoscope).

3. Electronic image transfer, electronic correlation (Gestalt Photo Mapper).

All five instruments were used in the production 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, photographed at a scale of 1:19 000, and having 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, agricultural 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 Territory. 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 orthophotos were brought to a common, enlarged scale for a comparison of the image quality.

The standard used for checking the accuracy 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 stereomodel 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 include 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

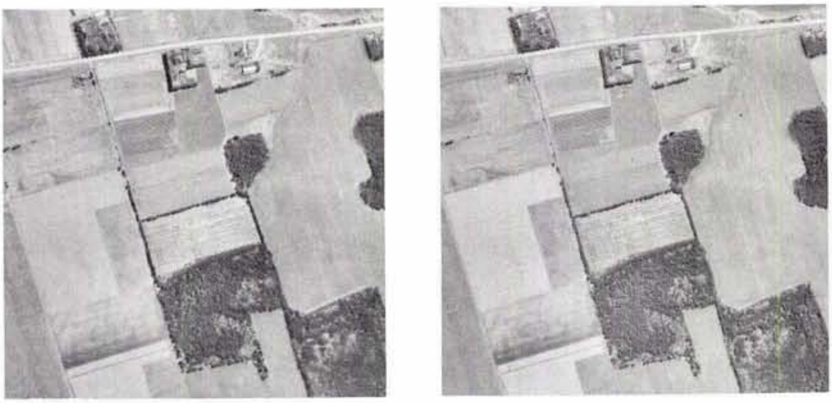
Most strip-scanning instruments use a slit with sloped ends (Figure 2) which provides an area of blending exposure between adjoining scans. The amount of this doubly-exposed area is usually about 5% of the total area. The SFOM used with a slit having a blending area of 10%, produced the most uniform 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 projected obliquely.

Scanning Difficulties in Mountainous Terrain

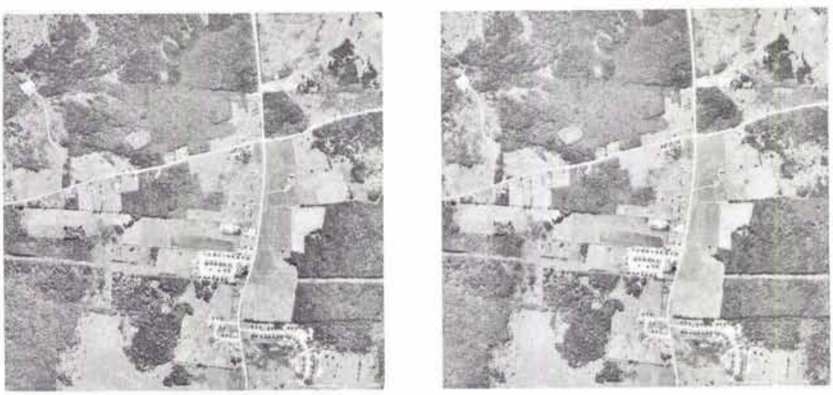
The mathematics of image displacement due to errors inherent in the scanning-slit method of differential rectification have been well documented by Ahrend[1] and Marsik,[4] but implied in the computation is a foreknowledge of terrain slopes and camera field angles which is usually not available at the planning stages of a mapping project.

Figure 3 shows the extent to which multiple images may occur on a 24° cross-slope at a field-angle of 35°. The unrectified imagery 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

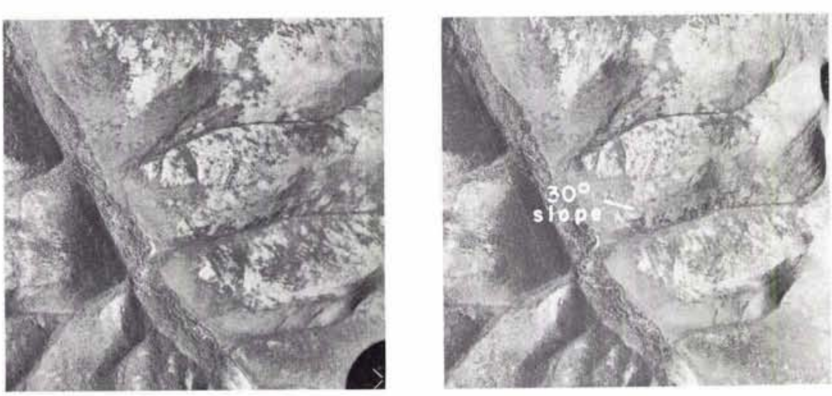
FIG. 1. Sections from test models.



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, $\Delta H = 13\%$

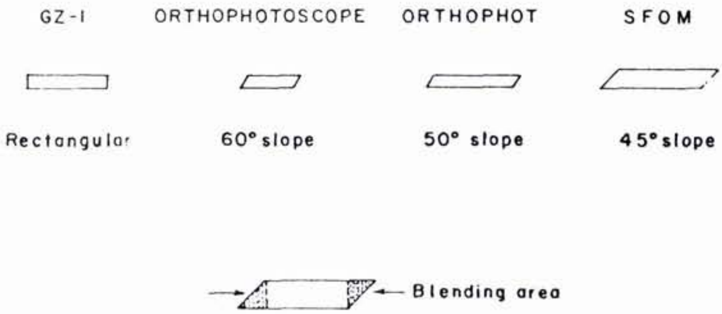
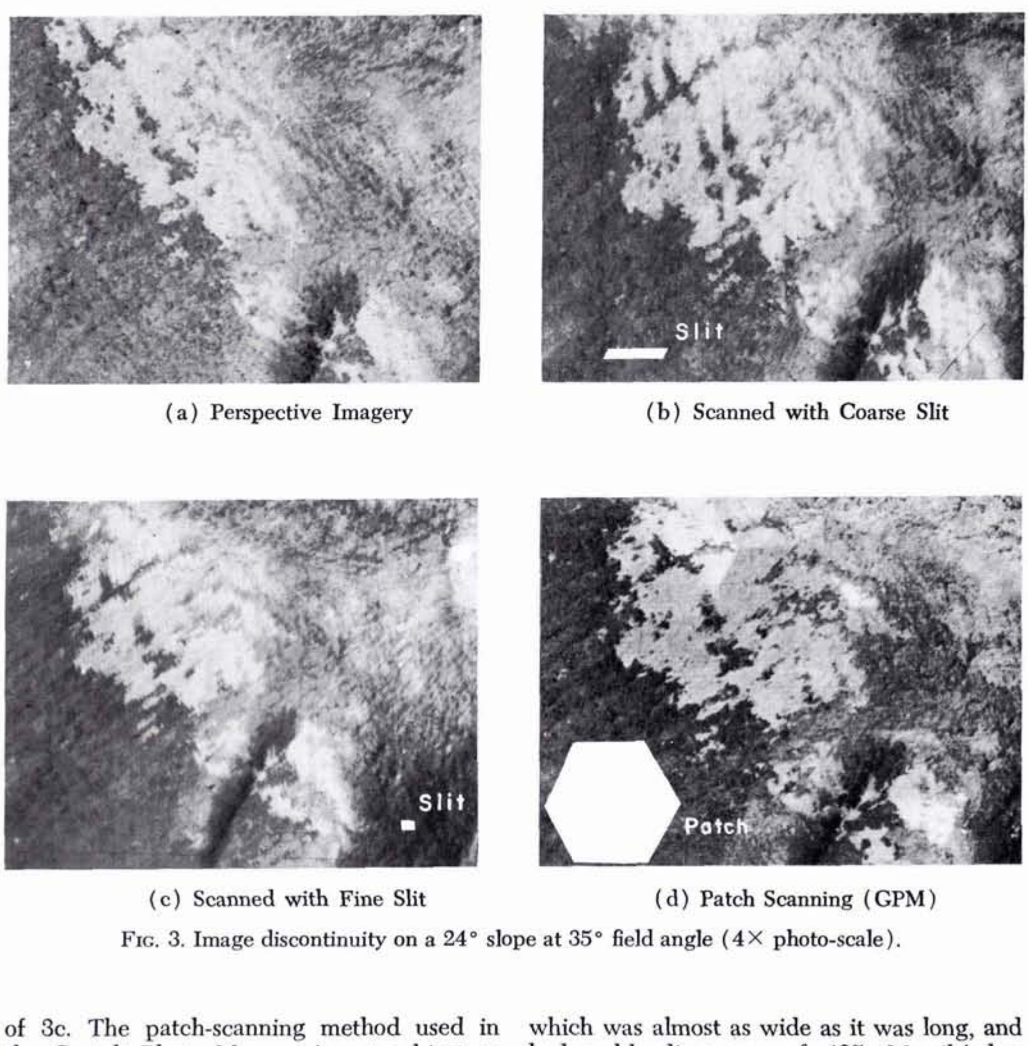


FIG. 2. Split shapes.



(a) Perspective Imagery

(b) Scanned with Coarse Slit

(c) Scanned with Fine Slit

(d) Patch Scanning (GPM)

FIG. 3. Image discontinuity on a 24° slope at 35° field angle (4× photo-scale).

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[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

FIG. 4. Multiple imagery.

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

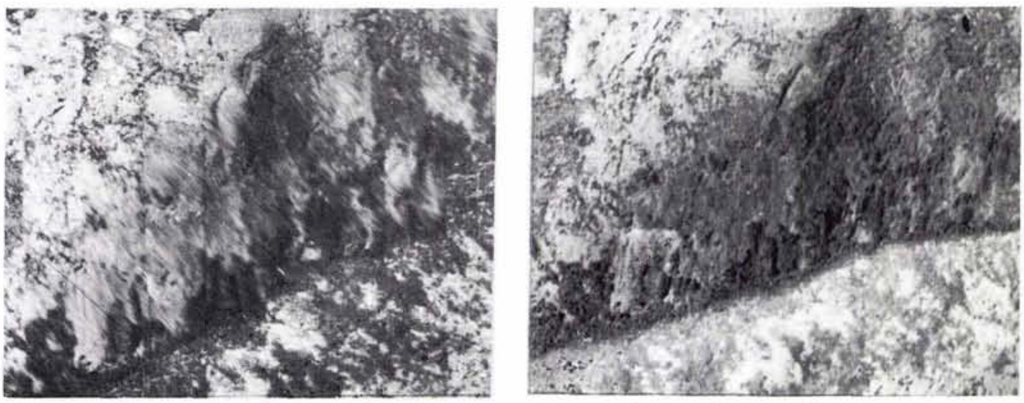
The rectifier and the differential rectifiers using sharp focus or electronic imagery produce a uniform image quality throughout their range of operation. The SFOM 693 Orthophotograph Unit and the Kelsh Orthophotoscope on the other hand depend on establishing a model scale at the optimum projection distance 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 over all 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.

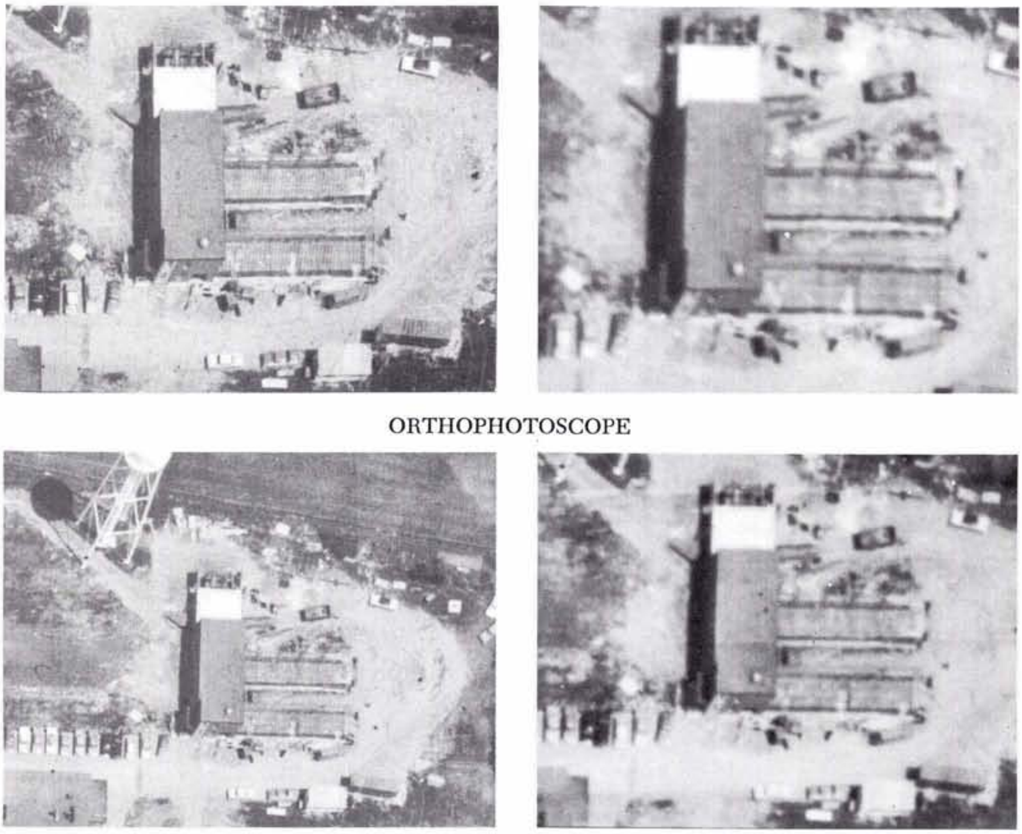
Collins and Kalensky[2] have studied the transfer of resolution in orthophotos from the negative to the orthophoto print, and Welch[7] has provided an application of MTF theory to this type of multiple reproduction. These researchers have indicated the magnitude of the loss of resolution at each reproduction 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-



Imagery from strip scanner | Imagery from patch scanner

FIG. 5. Blurring on a 30° slope (4× photo-scale).



Minimum Projection Distance

Maximum Projection Distance

FIG. 6. Optical imagery with depth of field SFOM.

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.

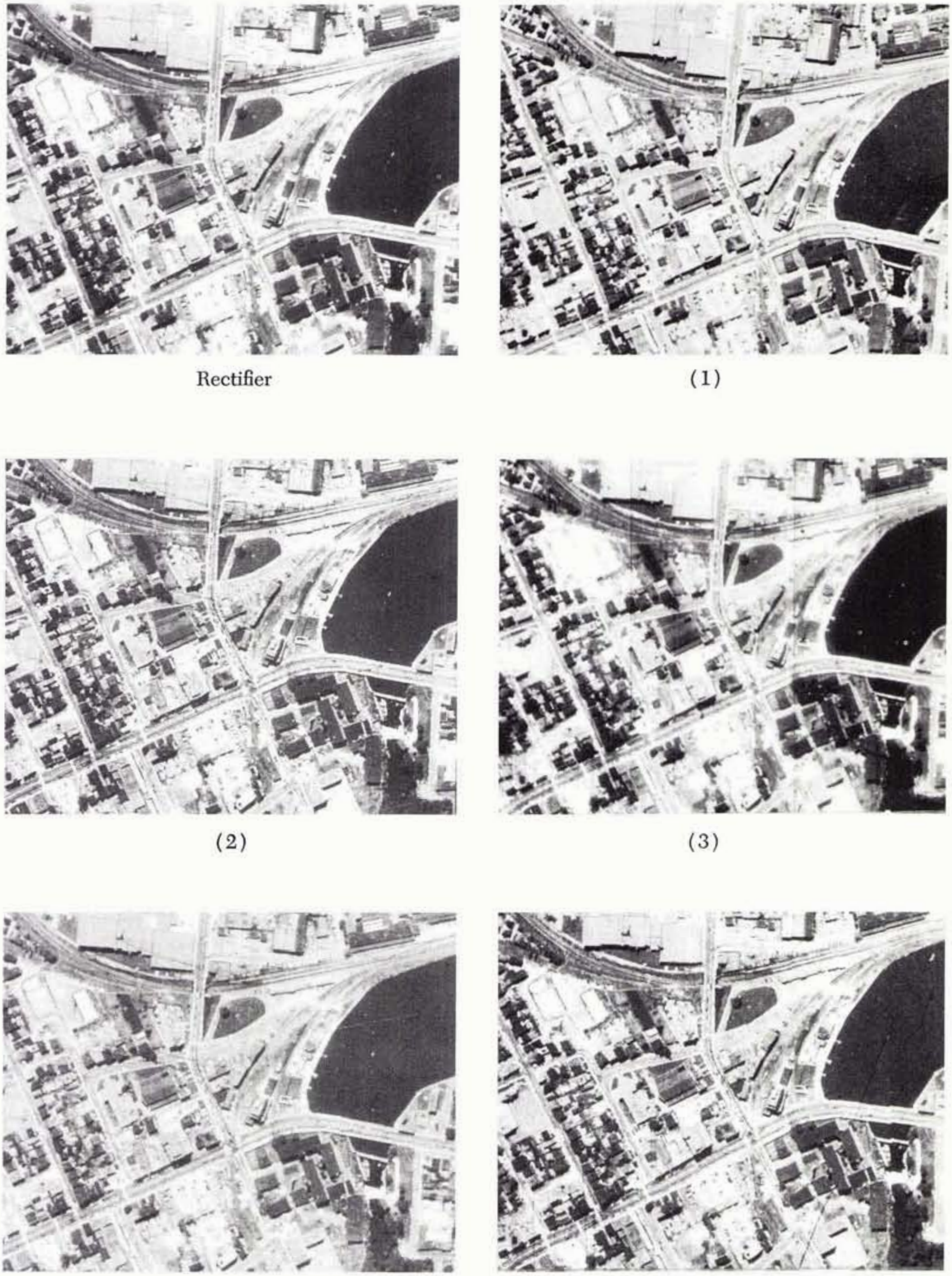
It was found that the dominant factor affecting the amount of detail and the appearance of the final reproduction was contrast. If the contrast is too high at any step, highlight detail is lost and never regained. If the contrast is too low the image lacks clarity for interpretation, and the appearance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



Rectifier (1)

(2) (3)

(4) (5)

FIG. 7. Orthophotos from six different instruments.

These sections are taken from 1:10,000 orthophotos (3.8 × 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

Elevation Difference % Flying Height		*Number Orthophotos Tested*	*RMS Deviation At Photo-scale* *Best*	*Worst*
Low relief	0.6%	4	0.04mm	0.06mm
	0.9%	4	0.04mm	0.06mm
Moderate relief	4%	7	0.03mm	0.06mm
Mountainous	13%	5	0.06mm	0.12mm
	12%	5	0.08mm	0.19mm (0.27mm)

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 (RMS) × 1.5174 = 0.09mm (CMAS)
Enlarged 5.5 × = 0.5mm (CMAS)

Mountainous:
0.20 (RMS) × 1.5174 = 0.3mm (CMAS)
Enlarged 1.6 × = 0.5mm

The deviations determined in this test for the low- and moderate-relief models correspond in magnitude with accuracy values given by Meier[5] in his analysis of the Gigas-Zeiss Orthoprojector in 1966, and Visser, van Wijk, van Zuylen and Mullen[6] in 1972

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.

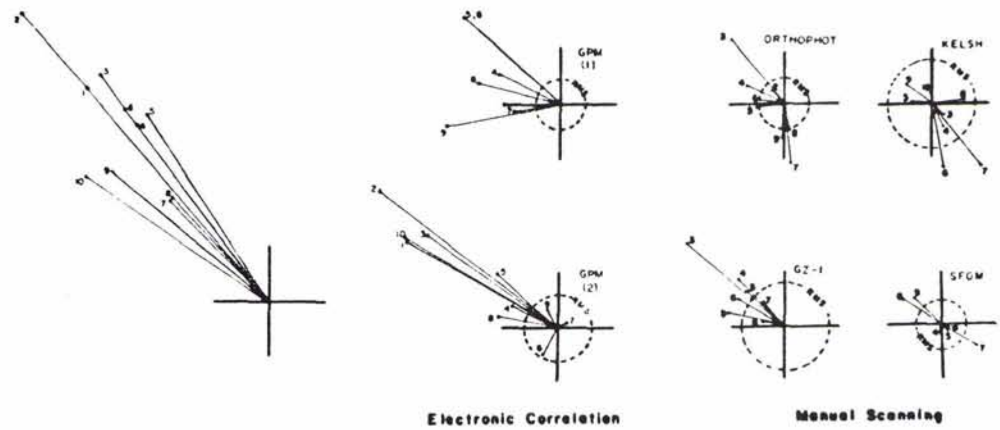
A compiler operating a strip-scanner on the other hand, will tend to go through the trees at what he estimates as ground level so that he will have the slit on the ground when he comes out the other side.

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 2. COMPUTED PHOTOMAP SCALE USING PLANE RECTIFICATION

Test Area	*Relief in the Area of the Photograph* Δh	*Computed Maximum Displacement**	*Photomap Where Maximum Dis-Placement = 0.5mm*
Low Relief	± 8.5m	± 5m	1:10 000
	± 12.5m	± 7m	1:14 000
Moderate Relief	±120 m	± 70m	1:140 000
Mountainous	±500 m	±291m	1:582 000
	±450 m	±262m	1:524 000

TABLE 3. POTENTIAL RECTIFICATION SCALE BASED ON MEASURED ERRORS

Test Area	*Photo-Scale*	*CMAS at Photo-Scale (Measured)*	*Enlargement Factor For CMAS = 0.5mm*	*Potential Map Scale*
Low Relief	1:19 000	0.085mm	5.9 ×	1:3 200
	1:19 000	0.18 mm	2.8 ×	1:6 800
Moderate Relief	1:38 000	0.38 mm	1.3 ×	1:29 200
Mountainous	1:50 000	2.87 mm	0.17×	1:295 000
	1:50 000	2.77 mm	0.18×	1.278 000

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.

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Articles for Next Month

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