Practical Photogrammetry from 35-mm Aerial Photography

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ABSTRACT: To date, photogrammetry has been primarily concerned with the analysis of 240-mm photographs or transparencies, taken with metric cameras. With advances in microcomputer controlled analytical steroplotters, 35-mm aerial photography can achieve acceptable levels of accuracy.
The photogrammetric accuracy of 35-mm aerial photography was analyzed using a modified Zeiss G-2 Stereocord. The imagery distortions were corrected using the analytical orientation procedures of the stereoplotting hardware-software system. Vertical measurements deviated not more than ± 0.001 of the flying height from ground truth values. These results are within precision standards for many practical photogrammetry applications.

INTRODUCTION

CURRENT HARDWARE and software improvements to microcomputer controlled stereoplotting systems permit greater photogrammetric accuracy (Hobbie, 1976). Using analytical methods, it is now possible to correct reconnaissance imagery with a microcomputer linked to a digital stereoplotter.

In conventional photogrammetric applications, 240-mm format metric photography is most widely used due to camera accuracy. The inner orientation is known and located through the use of fiducial marks; because radial distortion in metric cameras is often quite small, it can generally be disregarded for some photogrammetric applications (Torlegard, 1980). Although metric imagery is highly desirable, suitable photography is not always available for use. If existing aerial photography is not usable, new photography must be flown. The former alternative is preferred due to the cost of conventional aerial photography; however, existing photography may not meet the user's needs and a new aerial survey becomes necessary. With today's rising costs, this may not always be economically feasible. However, some photogrammetric projects could proceed using less expensive (non-metric) aerial photography and new photogrammetric plotting systems that can provide acceptable levels of accuracy at reduced hardware costs.

The main purpose of this study was to examine the accuracy of 35-mm aerial photography corrected for distortions using a microcomputer controlled analytical stereoplotter. The camera used (Nikon F-250) was non-metric, and there were no fiducial marks to determine the exact inner orientation. It was hypothesized that once the images were corrected, through the use of analytical methods, medium accuracy (± 0.001 of aircraft flying height) vertical measurements could be made from this small format (35-mm) reconnaissance photography.

The secondary goal was to compare the costs of this type of low precision aerial reconnaissance with metric photography. A cost analysis to compare 35-mm, 70-mm, and 240-mm format photography suggested that 35 mm would be most economical (Clegg and Scherz, 1975). It was believed that the cost structure of this photogrammetric project would be similar, with 35 mm being considerably less expensive than larger formats.

STUDY AREA

The study area, Bellingham, Washington (Figure 1 and Plate 1), was chosen for two reasons. First, costs were minimized because the same area was being used for another aerial photography project. Second, a base map with 5-foot contour intervals was available for the area; assuming these intervals to be accurate, they could be used as ground truth for a comparison study. In addition, this area was considered suitable because topographic relief was relatively low (overall height variation is less than 25 feet) and most of the land cover was pasture land and lawns. These relatively flat and visible surfaces would permit optimum stereoscopic viewing of the land surface, and distortions of the sloping terrain would be easy to identify.

PHOTO ACQUISITION

The aerial photography was flown in March 1983 using a rented Cessna 172 aircraft and commercially available photographic equipment. The camera was mounted on an external photomount and was electronically controlled from inside the aircraft (Plate 2). The lens used was a Nikkor 50-mm[1] *f*:1.4 with a

[1] The actual focal length of this Nikkor lens is published as 51.6 mm (Cooper and Abbott, 1969).

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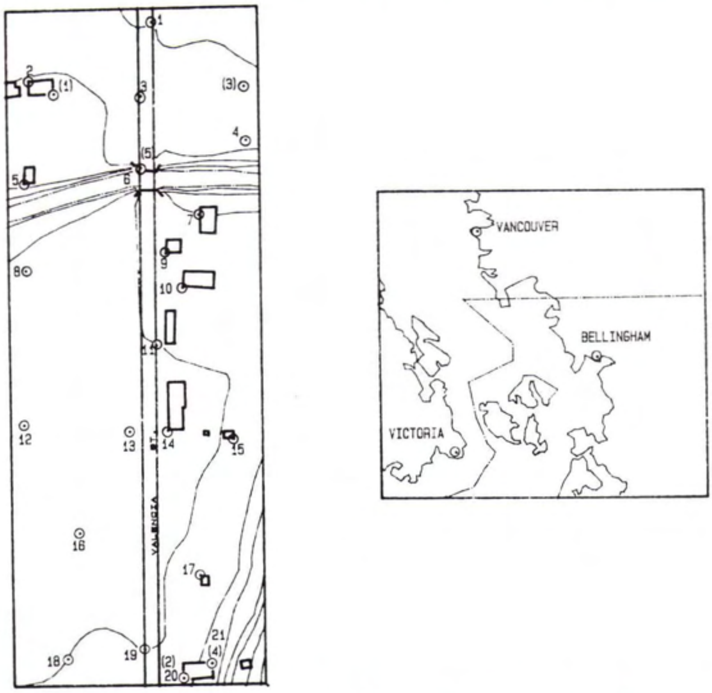

FIG. 1. Study area in Bellingham, Washington. Detailed map shows area of photo pair 21/22, indicating point locations for height measurement (1 to 21) and five ground control points (numbers 1 to 5 in brackets).

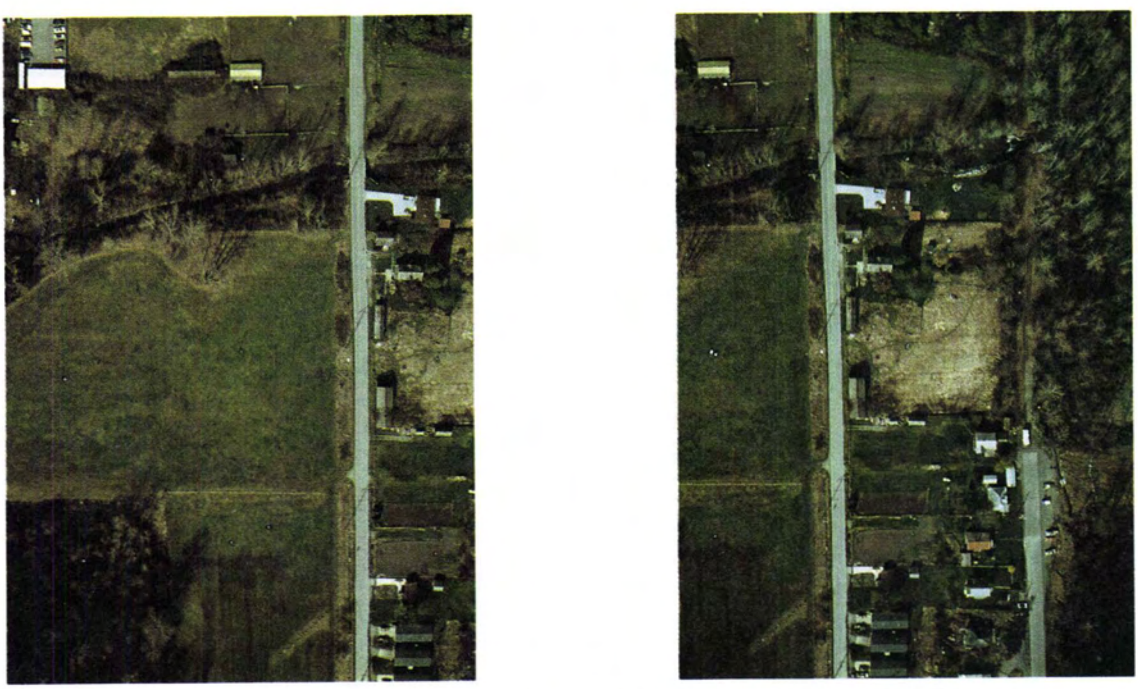

PLATE 1. Stereoscopic 35-mm reconnaissance aerial photographs of photo pair 21/22.

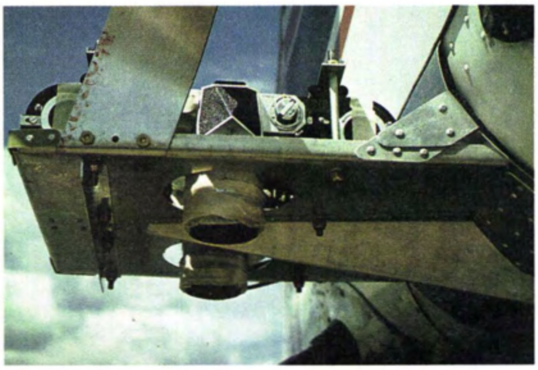

PLATE 2. Cessna 172 aircraft and portable external camera mount used for the reconnaissance aerial photography. Mount can be located on either side of the aircraft, takes two motor driven 35-mm cameras, and requires no modifications to any C-172 aircraft.

Nikon L1A filter. The film was Kodak 5036 Ektachrome color reversal. The photography was taken from approximately 2000 feet above ground, resulting in an average photographic scale of 1:11800. With 55 percent overlap, this resulted in a base-height ratio of approximately 0.21. This small base-height ratio resulted from using a transverse photographic mode (i.e., the flight line was across the short dimension (24 mm) of the 35-mm frame).

LABORATORY EQUIPMENT

The stereoplotter used to correct the photography and measure height was a modified Zeiss G-2 Stereocord (Hobbie, 1976). This unit was modified by Zeiss as a prototype G-3 Stereocord system to be fully capable of measuring y parallax. This stereoplotter was interfaced with a Hewlett Packard 9825T microcomputer which performed all analytical computations. The system software ('BOSS C') was modified to incorporate y-parallax corrections and provide "first order rectification" (Zeiss, nd.).

PHOTO PREPARATION

Original transparencies were used instead of prints so as not to lose accuracy. Goodrich (1982) demonstrated that serious distortions can be introduced into an enlarged 35-mm paper print. The transparencies were mounted, emulsion side down, onto index cards to allow easier handling.

Because the camera was non-metric, there were no fiducial marks to locate the principal point. Several analytical procedures could have been used (Livingston *et al.*, 1980; Wolf and Loomer, 1975), but a simple method to approximate the principal point by using the intersection of two diagonals from the corners of each transparency proved satisfactory.

To avoid drafting fine lines on the transparencies, these diagonals were established by using two taut strands of hair taped to the edges of the index cards. These were later removed once the principal point of the image was marked.

In order to follow the operating system software, the principal point, conjugate principal point, and four orientation points were located (Zeiss, nd.). Physical marks on the images would have reduced the total area visible for floating mark measurements; therefore, these points were indicated by small pinholes punctured into the transparencies, emulsion side down, using a fine straightpin. Although this slightly reduced the visible area, height measurements were still possible at these points.

Once the principal points and conjugate principal points were established, the flight lines were marked on the index cards. The transparencies were then mounted on the stereoplotter and the absolute stereoscopic parallax was measured using the plotter as a comparator.

IMAGE CORRECTIONS

The analytical removal of image distortions required nine known parameters. These were the actual camera lens focal length, aircraft flying height, absolute stereoscopic parallax, heights of three ground control points (within the viewable area), distance between two ground control points (fourth and fifth), and the measured XY coordinates of the fifth ground control point (Figure 1). The camera focal length was the only "known" parameter; the rest were calculated for each photo pair. Ground control was obtained from the base map and included three heights, the distance between the fourth and fifth points, and the XY coordinates of the fifth point. It was assumed that the base map represented the actual ground values. No lens distortion correction was used in the measurement procedure.

The nine orientation and control points were entered into the plotter program as the user followed relative and absolute orientation procedures established for the system (Zeiss, nd.).

After the corrected analytical model was established, a series of height measurements were made and compared with base map values. If the measured point did not fall directly on a map contour line, the height was approximated through linear interpolation.

For this study, three stereopairs were used. The points measured were each of the five ground control points and several points inside and outside of the area bounded by the control points (see Figure 1).

RESULTS

After data collection, statistical analyses were performed on each data group. The paired difference test was used to determine whether or not there was any significant difference in the measured heights from the stereoplotter and the base map heights for each of the three stereopairs (Ott, 1977).

Tables 1 and 2 show the measured heights, the base map heights, and the results of the statistical analyses. Although there were some significant differences between the ground values and the measured elevations from the corrected 35 mm aerial photography, these differences were minor and generally less than 0.6 feet. The test statistic (t) was computed for each photo pair and compared to the corresponding critical values (t'). For two cases the computed statistic (t) was smaller than the critical value (t'), indicating that the measured points were statistically identical to those on the base map. In the third case (photo pair 9/10) the computed value of t indicated a significant difference between the height values on the maps and from the corrected stereo model. However, the average difference was less than 0.4 feet, the largest difference was 1.89 feet, and the standard deviation was 0.5 feet; for aerial photography taken from 2000 feet, this is an average accuracy of 0.0002 times the flying height, with the greatest error still less than 0.001 times the flying height. For practical purposes the elevation differences between the map values and photogrammetric measurements are minor and will satisfy most non-precision photogrammetric requirements.

Because there may have existed some pattern to account for the differences in measurement, the residuals between the photogrammetric heights and map height for each point were mapped for each stereoscopic pair (Figure 2). The residual height values for each stereoscopic model were recorded, perpendicular to the flight line, and the values were plotted onto a graph (Figure 3). The same procedure was performed across these models, parallel to the flight lines.

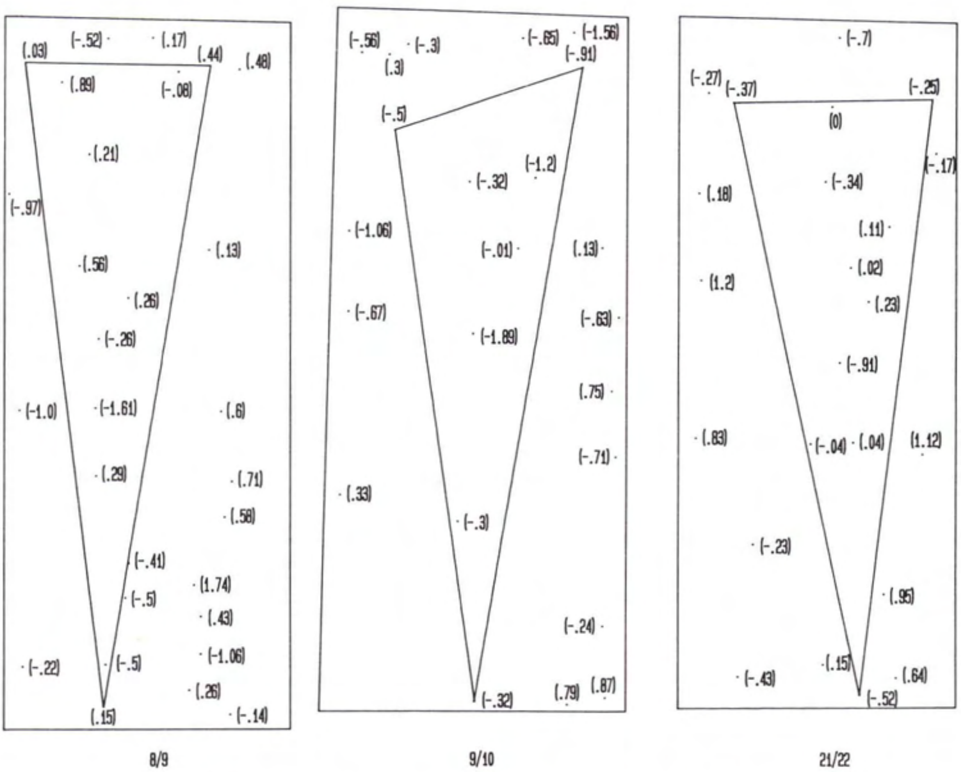

FIG.2. Maps of height measurement residuals for each of the three stereo pairs (8/9, 9/10, 21/22) used in the study. Values are given in feet + or − the ground truth values. Triangles indicate the area inside the vertical control points.

TABLE 1. COMPARISON BETWEEN GROUND TRUTH (MAP HEIGHTS) AND PHOTOGRAMMETRIC MEASUREMENTS (PHOTO HEIGHT) FROM THE 35-MM RECONNAISSANCE AERIAL PHOTOGRAPHY. HEIGHTS ARE IN FEET.

	Photo Pair 8/9			Photo Pair 9/10			Photo Pair 21/22	
Point	Map Height	Photo Height	Point	Map Height	Photo Height	Point	Map Height	Photo Height
1	78.85	78.82	1	72.50	72.80	1	80.00	80.70
2	80.48	79.59	2	80.00	81.56	2	74.79	75.06
3	82.88	83.40	3	75.00	75.32	3	76.50	76.50
4	85.00	84.83	4	70.00	71.06	4	75.59	75.76
5	87.50	87.58	5	72.50	72.51	5	70.21	70.03
6	95.00	94.56	6	75.00	74.87	6	75.00	75.34
7	95.00	94.52	7	65.00	65.67	7	75.00	74.89
8	80.00	79.79	8	70.00	71.89	8	70.63	69.43
9	75.00	75.97	9	70.00	69.67	9	76.07	76.05
10	75.00	74.44	10	72.50	72.80	10	76.67	76.44
11	75.00	74.87	11	75.00	74.25	11	75.00	75.91
12	75.00	74.74	12	75.00	75.24	12	72.33	71.50
13	76.13	77.39	13	80.00	79.13	13	73.63	73.67
14	73.02	74.02	14	77.00	77.65	14	74.17	74.13
15	75.00	76.61	15	72.50	73.00	15	76.50	75.38
16	85.00	84.40	16	72.00	72.56	16	73.63	73.86
17	74.12	73.83	17	72.88	72.58	17	77.67	76.72
18	100.00	99.29	18	80.46	81.37	18	75.00	75.43
19	102.50	101.92	19	75.00	76.20	19	75.00	74.85
20	77.50	77.91	20	75.00	75.63	20	79.23	79.75
21	77.50	78.00	21	74.14	74.85	21	83.33	82.69
22	100.00	98.26	22	79.17	79.49			
23	105.00	104.57	23	81.76	80.97			
24	76.00	76.22						
25	78.50	79.00						
26	104.29	105.35						
27	80.00	79.85						
28	110.00	109.74						
29	122.50	122.64						

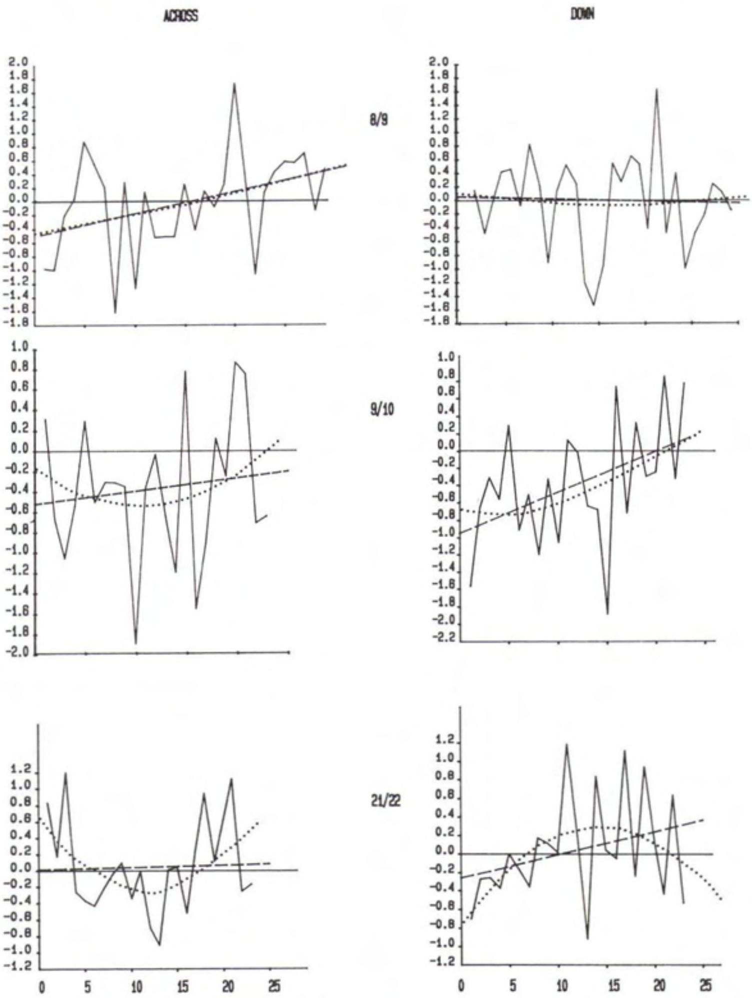

FIG.3. Graphic plots of residual height measurement values from Figure 2. Results are plotted "across" and "down" each stereo model for the three photo pairs. Values are in feet. Dashed line indicates linear regression fit and dotted line indicates best fit for a parabolic regression.

TABLE 2. RESULTS OF "*t*" TESTS COMPARING PHOTOGRAMMETRIC MEASUREMENTS WITH BASE MAP (GROUND TRUTH VALUES).

Photo Pair	t	t'
8/9	−0.1214	1.701
9/10	−3.5869	1.717
21/22	0.8129	1.717

An examination of these graphs reveals some systematic distortions in each stereoscopic model. The image pair 21/22 shows a distinct positive-negative-positive trend with a good parabolic fit. The source(s) for these errors are not known but they probably result from warping of the original transparencies in their mounts, lack of precise interior orientation information for the lens-camera system, ground observation (map) errors, or any combination of the above. The relatively low error level with a mean height variation from the ground values of ± 0.56 feet and a maximum error of 1.89 feet indicates that the system is capable of performing with an error factor of less than 0.001 of the flying height of the aircraft.

COST COMPARISONS

A brief examination of comparative hardware, aircraft, and photography expenses shows that 35-

TABLE 3. COST COMPARISON OF 240-MM, 70-MM, AND 35-MM AERIAL PHOTOGRAPHY SYSTEMS (BASED ON 1984 CANADIAN PRICES).

	Zeiss RMK 24cm 6″ lens	Hasselblad EM500 70mm 100mm lens	Nikon F-3(250) 35mm 50mm lens
Basic Camera System	$145,000.00	$5,000.00	$2,500.00
Minimum A/C Required	$150.00/hr	$ 100.00/hr	$ 50.00/hr
Color IR film	× 125′	× 100′	× 100′
cost per roll	$ 530.00	$ 130.00	$ 65.00
cost per photo	$ 3.50	$ 0.30	$ 0.08
EKTACHROME film	× 125′	× 150′	× 100′
cost per roll	$ 450.00	$ 160.00	$ 50.00
cost per photo	$ 3.00	$ 0.23	$ 0.07
B & W IR film	× 250′	× 150′	× 100′
cost per roll	$ 515.00	$ 95.00	$ 50.00
cost per photo	$ 1.75	$ 0.14	$ 0.07
Plus X Pan Film	× 250′	× 150′	× 100′
cost per roll	$ 265.00	$ 52.00	$ 20.00
cost per photo	$ 0.98	$ 0.07	$ 0.03
Color Processing	$ 1.50/ft.	$ 1.50/ft.	$ 0.87/ft.
B & W Processing	$ 0.80/ft.	$ 0.80/ft.	0 .80/ft.

mm and 70-mm systems are considerably more economical than 240-mm systems (Table 3). In addition, 35-mm systems are usually at least twice as economical as 70-mm systems at the same scale. For reconnaissance photography purposes, over smaller study areas, this small format photography is considerably more cost effective. For larger areas it is recommended that 240-mm format photography be used for mapping coverage. The area covered by one stereoscopic pair of 240-mm photographs requires 28 70-mm photographs or 150 35-mm photographs for the same stereoscopic coverage. Not only are the film costs somewhat higher for the small format photography but the photo interpreter will be required to examine many more individual images (although the actual total area of stereoscopic coverage will be the same).

DISCUSSION

The results indicate that practical photogrammetry can be done using 35-mm aerial photography and a microcomputer controlled analytical stereoplotter. Although some systematic errors are present in the plotted values, the magnitudes of the errors are low. These accuracy levels are acceptable for many photogrammetric purposes.

The total cost of this project for aircraft rental, film, and processing was approximately $50.00 (Canadian) for 40 stereopairs covering 5.2 sq km. Because the aircraft required no modification, any Cessna 172 could be rented, and the 35-mm Nikon F-250 camera and aircraft mount involved a very small capital investment (less than $2500.00). By comparison, 240-mm or 70-mm photography would not have used more film but would have required a greater initial film investment (e.g., $450.00 for nine 1/2 in. by 125 ft) and a considerably greater capital investment for cameras and installation. Because these larger formats require an aircraft with a photo hatch and appropriate 24 or 12 volt power, aircraft availability is reduced and the cost is increased. Although it is not possible to give exact costs on this project for comparable coverage using other systems, it is clear that the 35-mm system is most economical for similar small reconnaissance photography missions. This cost efficiency should be attractive to most users and could "open the door" for low precision photogrammetric and photo interpretive applications.

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