Measuring from long range oblique photography (LOROP)

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ABSTRACT

Long Range Oblique Photography (LOROP) has been investigated briefly as a means of collecting quantitative data about very distant scenes. Two measuring aspects are discussed: first, producing dimensional data about the sizes and heights of man-made objects, and, secondly, measuring the geographic location of an object. This latter task is rather new for the photo intelligence specialist, who in the past generally did not have available these photogrammetric capabilities.

We show in this contribution that at stand-off distances of 130 kms (80 miles), a position can be routinely measured with an accuracy better than ±10 m, in less than 15 minutes.

1. Introduction

The end goal of all photo reconnaissance collection equipment (including aircraft and crew, cameras, electronics, photo lab, etc.) is to deliver a quality image to the photo intelligence specialist. Once this is done, his task is to study the imagery, extract the intelligence information, and communicate it effectively into the system. The information which he produces can usually be categorized under one of the following headings:

- inventory of the military equipment at a site;
- activity status of a known target;
- description of a newly discovered facility;
- dimensioning ground facilities or equipment;
- geographic location of a new target.

The first three items in the list have been quite standard for most military Photo Interpreters (or "Image Analysts") ever since the blossoming of photo intelligence capabilities during World War II. These capabilities are taken for granted, whether from vertical photography from oblique or other images. The fourth item in the list, dimensioning, has been very much less practiced during interpretation work from oblique images. The techniques are taught in most rigorous Photo Interpretaion (PI) courses. They are also available in PI reference books such as those included in the references. However, the techniques are slow and awkward, and are very susceptible to arithmetical blunders. Thus, for the most part, dimensioning from oblique photography has been practiced for training purposes, but only rarely in reconnaissance operation where time pressures exist.

The last task in the list above, determining geographic location of a target, has not been practiced at all by photo interpreters, as a measuring process from an image. The best he could generally do was to "eyeball" the target's approximate location onto a reference map, and then extract the geographic coordinates from the map, for use in the photo intelligence reporting cycle.

In the past, the image analyst did not produce much dimensional and positional intelligence from oblique photography, not because it is not needed, but because he could not. As a result of the mensuration light table and the microcomputer, all of this is changing. It is our contention that, as a result of these new capabilities (implemented in smooth and efficient hardware and software), the PI will be expected to routinely produce much more numerical data. The quality of that numerical data should begin to come close to matching that which a photogrammetrist could produce from the same photography but specialized photogrammetric precision equipment.

We have previously studied the feasibility of photogrammetric precision measurements from LOROP and found that such imagery can be used for position measurements (Ref. 3). We subsequently implemented an operational system within a photo-interpretation station (Ref. 4).

The current paper is concerned with reporting some experimental results of these types of measurements from LOROP imagery in a photo interpretation environment.

2. Equipment used

All measuring was done using the VIDARS (Video Display, Analysis and Recording Station) photo interpretation work station built by the Richards Corporation (McLean, Virginia) and VEXCEL Corporation (Boulder, Colorado). VIDARS is composed of a set of building blocks as shown in Figure 1. Two different implementations were used for the experiments reported here. For research purposes, James Madison University (Northern Virginia) operates a VIDARS prototype made available by the Richards Corporation. It consists of a MiM-2 light table with mensuration scales on the carriage, a Bausch and Lomb Zoom-70 stereoscope with a crosshair in the right eyepiece, an embedded microcomputer for communications purposes, and a printing terminal. The RS-232 output of the microcomputer sends image coordinates to the host computer elsewhere on campus, in this case, a VAX 8600. The software is resident on the VAX and interacts smoothly with the terminal and the digitizing system on the light table.

A production implementation of VIDARS is in use at VEXCEL Corporation at Boulder, Colorado. This unit is identical to systems already commercially delivered. It currently consists of a Richards Corporation HFO-type light table with a fixed video camera mounted above it, a DEC PDP-11 microcomputer, and the usual peripheral devices. When the operator looks at the video display he sees up to a 130X magnification of the film on the light table, with a crossphair display at the screen center. One of the peripherals is a Honeywell dry silver hardcopy device for producing annotated photographs to accompany the intelligence reports generated using the system. Both VIDARS versions involve equipment which is fully integrated, so that each part of the system can communicate directly with the other parts as needed.

3. Dimensioning ground Objects from LOROP film

3.1 Oblique metrics

The procedures involved in dimensioning ground objects from oblique photography are well known. They are generally grouped together under the name "oblique metrics". The standard formulas provide methods for photo interpreters to graphically determine the true depression angle of the camera under various conditions, and using this to measure the size of objects on the ground. This dimensioning of ground ojects requires three pieces of reference information about the oblique airphoto: camera focal length, flying height, and depression angle. If this input data is reasonably accurate, then photo interpreters have been accustomed to producing measurements which are in error by no more than about five precent or so. In some of the military PI training courses, two to three percent is used as a threshold for very satisfactory mensuration depending on the particular kind of mensuration task. We will refer to dimension measurements also as "PI mensuration". This is in contrast to "position measurement" or "photogrammetric positioning".

Typically one expects this to be carried out using common reconnaissance cameras at focal lengths of 6" or so. How does "oblique metrics" change when we try to do the same thing from LOROP images, where the object measured may be fifty miles or more from the flight line?

3.2 Oblique metrics from LOROP

There are two primary differences between oblique metric cameras and LOROP. First, because the object is so far from the aircraft, we may have to account for earth curvature in our formulas. Second, because of the small format of the airphoto, and the small scale at the target, measuring from the image by hand (using a boxwood measuring scale or whatever) becomes very awkward, except for very large objects such as the length of a long runway at an airfield. Even in this case, however, manual measuring from this type of imagery in the intelligence production environment is impractical. We need equipment which will allow us to quickly measure very small image distances with very small errors.

In the computerized photo-analysis environment there exists no need to actually implement the classical algorithms of military PI handbooks. Instead one can use rigorous photogrammetric transformations from image to object space. The separation into "PI routines" and "photogrammetric software" becomes redundant. As a result, the PI has available the tools of rigorous photogrammetry without a need to understand them or even to be aware of their existence.

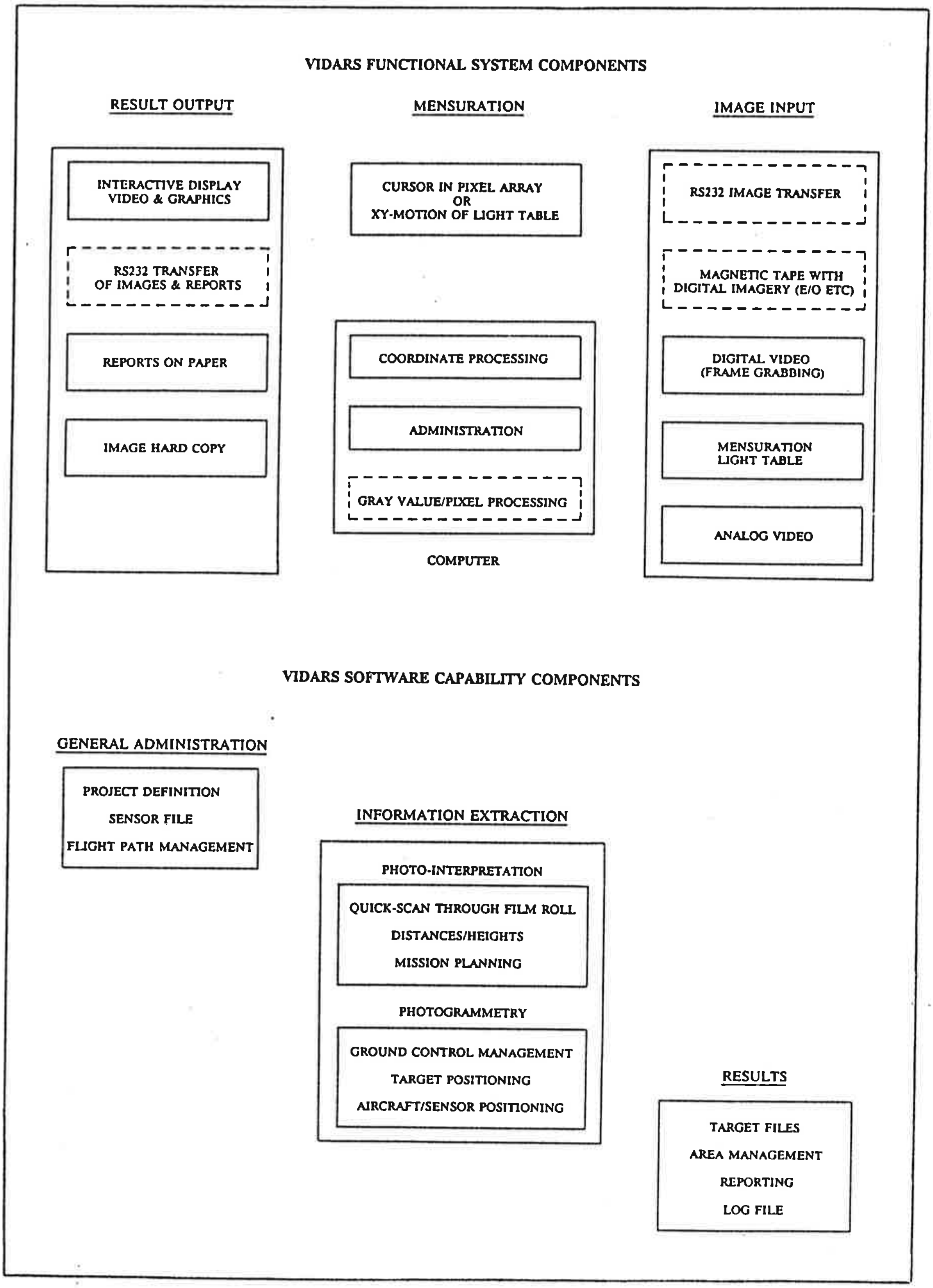


Figure 1: Building blocks of the VIDARS workstation

3.3 Test images

In order to test the ability to dimension ground objects from LOROP images using VIDARS, four different LOROP images were used, and extensively documented (see Table 1). The images range from a 24-inch focal length panoramic sector scan image to a 66-inch LOROP frame camera. The latter was flown at about 58,000 feet for one of the images used. Thus, the testing was done on typical as well as extreme standoff imagery.

3.4 Measurements and computations

On each image, several distances or object heights had been determined previously as ground truth by independent precision measurements from maps, National High Altitude Photography (NHAP) or from other sources. NHAP images were measured in a so-called photogrammetric analytical stereoplotter. These same distances were then measured numerous times from LOROP and compared with the correct values. The results are summarized in Tables 2 and 3. Unless otherwise indicated in the charts, all measurements are in meters. The percent error is also expressed in the tables.

The measuring process can be performed in one of two ways: First, the answer can be calculated using as inputs the nominal flight data (Table 2). By "nominal" we mean the desired or planned flying height, and the indicated depression angle, possibly from the data block if the camera had one; otherwise, the intended camera depression. Second, the flight data can be computed using a rigorous photogrammetric solution based on ground control points (Table 3).

Test Area	Type of Imagery	Focal Length [inch]	Approximate Flying Height [km]	Approximate Depression Angle (°)	Approximate Standoff [km]
Dallas	LOROP	66	11.0	16.5	40.0
Ft. Worth	LOROP	66	18.0	8.5	130.0
Torrance	LOROP	66	6.0	21.5	16.0
Barstow	Sector Scan	24	10.0	40.0	12.0

Table 1: Parameters of test imagery.

Type of Imagery	Short Distance (M)	Error		Long Distance (M)	Error		Error per stand-off distance	
		(M)	%		(M)	%	Short Distance	Long Distance
Dallas	504	-47.	9.3	4308	-211	4.9	0.12%	0.53%
Ft. Worth	468.0	-40.0	8.5	2136.0	-221	10.3	0.03%	0.17%
Torrance	382.2	+9.6	2.5	1238.0	-53.0	4.3	0.06%	0.33%
Barstow	585.0	+12.	2.0	1320.0	+36.0	2.7	0.10%	0.30%

Table 2: Results of distance measurements with only nominal values for flight altitude and depression angle.

Type of Imagery	Short Distance (M)	Error (M) /	%	Long Distance (M)	Error (M) /	%	Error per stand-off distance Short Distance	Long Distance
Dallas	504	-5.0	1.0	4308	-6.0	0.14	0.013%	0.015%
Ft. Worth	468.0	+7.0	1.5	2136.	-22.	1.0	0.005%	0.017%
Torrance	382.2	+3.5	0.9	1238.0	-3.0	0.25	0.022%	0.020%
Barstow	595.	-2.0	0.35	1320.0	-6.0	0.45	0.018%	0.050%

Table 3: Results of distance measurements with correct values for flight altitude and depression angle. Computations are based on use of ground control points.

4. Interpretation of LOROP PI mensuration results

4.1 Results using nominal camera altitude and depression angle

Despite the small scale of the photograpy, and the great distance to the target, it appears that the normal accuracies expected in photo intelligence exploitation work can almost be maintained. For measuring horizontal distances and the height of vertical objects, the worst result was an error of about 200 meters for a 2136 meter object, twenty miles from the flight line of the aircraft. That is about a 10 percent error.

The reasons for these errors relate to the assumption of camera attitude and flying height.

4.2 Measuring process with nominal camera altitude and depression angle

The accuracies are determined without any ground control. We are dealing with a photo interpretation process which is easily learned by any PI, can be carried out at the same mensuration light table used for the conventional PI work, and can be done very quickly. Such measuring sessions typically take an experienced operator anywhere from four to eight minutes. This includes the entire mensuration process as follows:

- input flight parameters at keyboard (if none already available in the data base),
- digitize the fiducials,
- digitize the two end points of the target,
- compute and display the answer.

If greater accuracy is needed, and if ground control points are available, the photo interpreter can take a few additional minutes to first orient the image to the ground photogrammetrically, then measure the necessary dimensions. An experienced operator can typically accomplish all of this in six to ten minutes. The expected accuracies for this type of work are discussed in the next section of the paper.

4.3 Results using correct flight parameters

Table 3 repeats the results of Table 2 with the difference that the nominal flight data is replaced by photogrammetrically determined altitude and depression. The improvements here, of course, depend on how badly off the nominal values were. In the cases considered here, we found discrepancies in altitude of one to three thousand feet and one or two degrees in the camera depression angle. In general, these input errors tended to double or triple the error in the final answer.

One concludes from this that ideally and for best results the photo interpreter should have available to him a data block on each exposure indicating the correct radar altitude and the camera depression, accounting for roll of the aircraft. If such information is not available, then ground control can still enable the photo interpreter to quickly produce reliable dimensions from LOROP imagery. In tactical reconnaissance, the aircraft and sensor package are commonly not far enough developed to include radar altitude and true depression; also, the reliability of these displays has sometimes been a problem.

4.4 Discussion

Perhaps a concluding example will draw together and illustrate the simple dimension measuring capabilities without ground control and without data block. Using the Fort Worth LOROP imagery indicated in Table 2, a fourteen thousand feet runway was measured. The resulting answer was 372 feet short, or about 3%. The target itself is at a standoff of 80 miles, and measures only about 3/8 inch in length on the film. Considering the photographic conditions and the fact that the photo interpreter can easily do this in four to six minutes, the result must be considered more than satisfactory for the needs of tactical intelligence.

5. Geographic position finding from LOROP film

5.1 Definition of the problem

The measuring work described above is all based on internal information within the aircraft (altitude and depression) rather than any knowledge of the true position of the aircraft in three-dimensional space. In order to find geographic coordinates for targets on the image, we must have information about the camera position. In the current experiments this was found from control points, visible on the image, for which we know the proper ground coordinates. These points then form the basis for computing where in space the aircraft had to be in order to produce the ground pattern of points observed on the film. This process is called "orienting" or registering the photo to the ground. The photogrammetric technique is also called "resection-in-space". Once the exact position of the aircraft and the orientation of the camera lens are known, any other point on that exposure or neighboring exposures can be plotted to about the same accuracy.

The process of plotting the geographic coordinates of a new target from a piece of LOROP film consists of the following basic steps:

- input the nominal flight parameters at the keyboard if this has not already been done (focal length and loose approximations for camera depression and aircraft altitude);
- digitize fiducial marks;
- identify and digitize at least three ground control points which are in the geographic data base for the area;
- digitize the target.

Naturally, as more control points are used, the solution converges to a closer approximation for the true position of the aircraft. Although the software will function with only three control points, we have considered five well-distributed control points over the image format to be a minimum to have a protection against mis-identification and error.

5.2 Results

The test process has basically involved orienting the photo using four to ten ground control points, and then testing on other known points. A summary of the results of these tests is to be found in Tables 4 and 5.

Best results for accurate target plotting are obtained if an accurate ground control file was produced. In the current case vertical aerial photography of the area was used on a precision stereoplotter to obtain accurate control. Also, ground coordinates were digitized from the 1:24,000 U.S. Geological Survey maps of the area. Naturally the points contain various kinds of error. These include:

- * errors of identification (where is the center of a road intersection?);
- * errors of the map.

In a study of the statistical accuracy of U.S. Geological Survey 1:24,000 maps, numerical test data were compiled by the USGS on 343 test points scattered over thirty mapping projects. The result was a root mean square positional error of lines on the map of about 7 meters (Ref. 5).

Imagery	Residuals (m)in Ground Control X	Y	No. of Ground Control	Error (m) of Targets X	Y	No. of Targets	Relative Error per Stand-off Distance(%)	Comment
Torrance	3.9	1.8	4	6.0	5.7	19	0.052%	
Dallas	4.9	9.3	11	2.8	7.1	10	0.019%	
Ft. Worth	4.0	7.1	4	9.1	10.4	11	0.011%	
Barstow	6.9	14.0	9	11.3	31.8	29	0.265%	Points spread over 30° scan angle
Barstow	4.5	4.1	4	7.8	6.4	9	0.084%	All points clustered

Table 4: Results of LOROP target positioning using ground control points measured off a map at scale 1:24,000.

Imagery	Residuals (m)in Ground Control X	Y	No. of Ground Control	Error (m) of Targets X	Y	No. of Targets	Relative Error per Stand-off Distance(%)	Comment
Torrance	2.3	1.5	8	3.5	3.1	18	0.022	

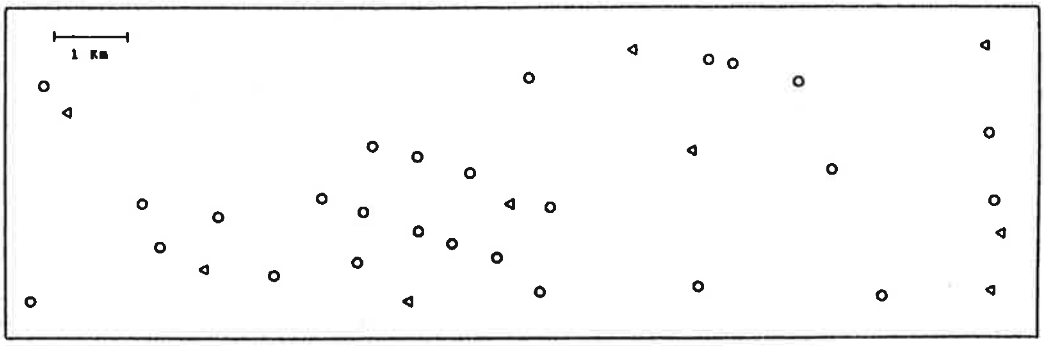
Table 5: Results of LOROP target positioning using ground control points measured off aerial photography (National High Altitude Photography at scale 1:80,000).

For the Fort Worth case, we obtained positional errors of 9 meters in x, 10 meters in y respectively. Given a standoff distance of 130 kms we deal with a relative accuracy of 1 part in 10,000. When judging the results, it is important to keep in mind the imaging and measuring conditions (given for the Fort Worth imagery):

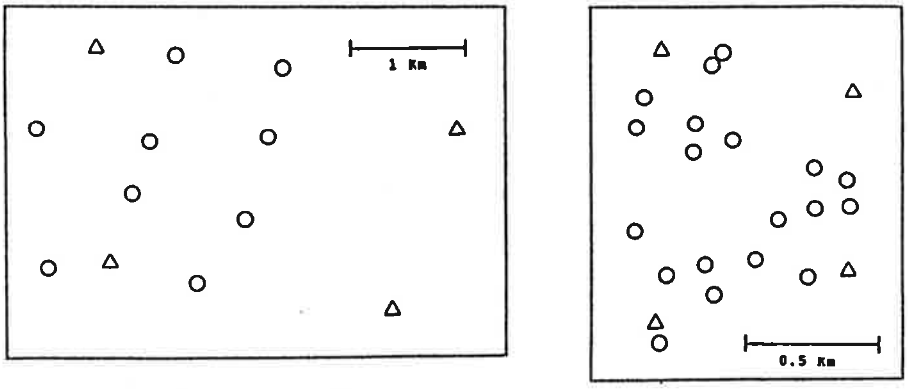
- reconnaissance camera with no effort at geometric calibration (as with mapping cameras);
- flying height of eighteen kilometers;
- standoff of 130 kilometers;
- processing time of approximately ten minutes;
- very minimal operator training required for experienced photo interpreters.

For the Dallas case, we were able to plot the locations of unknown targets on the image within a standard deviation compared to their map position of about 8 meters. This means, for example, that the UTM ground coordinate for about two thirds of these targets are in error by eight meters or less when compared to the map. The map error does not permit us to obtain a more relevant accuracy statement for the LOROP data. Statistical theory also allows us to infer that the worst error we can reasonably expect here is about three times that value, or approximately 24 meters.

For the Torrance test area we had two sets of ground control points available. One set of control data was derived from 1:24,000 USGS maps and a second set of control data was mesured from NHAP imagery using a photogrammetric analytical stereoplotter. In the first case (map derived control data) we were able to achieve an accuracy of ± 8 meters. In the second case, using the more accurate NHAP control data, the standard deviation of the position of new targets was ± 4.7 meters (±3.5m in X, ±3.1m in Y).

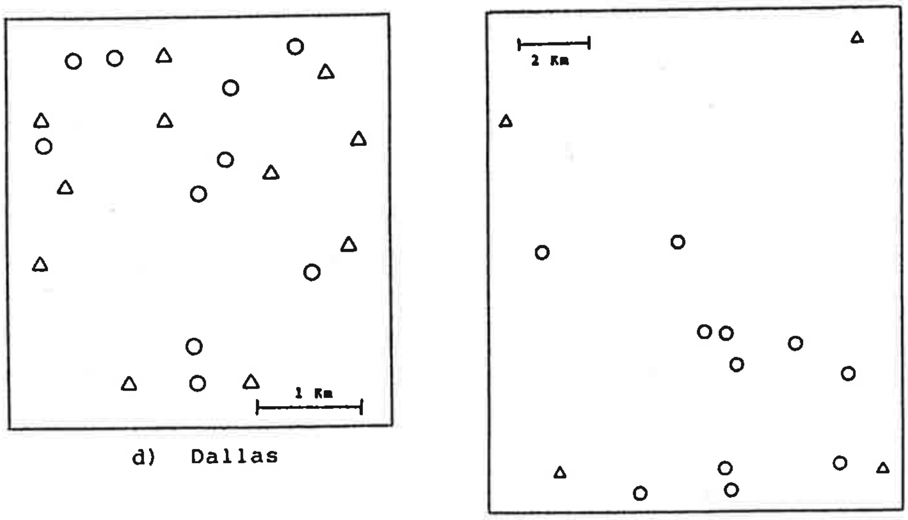


a) Barstow #1



b) Barstow #2

c) Torrance



d) Dallas

e) Ft. Worth

Δ = Ground Control Points
O = Targets

Figure 2: Ground Control and Target Distributions

The area of Barstow is covered by a sector scan panoramic image. Using four closely grouped ground control points we can position a set of targets with r.m.s. errors of less than ±10 m (±7.8 m in x, 6.4 m in y). With ground control spread loosely over the entire scan (30° sector scan), target positions have errors of ±11 m along flight and ±31.8 m across the flight direction.

Ground control distributions are shown in Figure 2.

6. Conclusions

Using actual LOROP imagery, the ability of a photo interpreter to produce various kinds of measurements has been tested. The "oblique metrics" results he is acquainted with are available from the computer driven system. When this system is used on long range photography, the results seem to support the conventional accuracy expectations from short focal length oblique imagery very well, despite the much more difficult imaging and viewing conditions.

In general, photo interpreters can expect to dimension ground objects such as runways, ships, large aircraft, and antennas on LOROP imagery to within two to six percent of their true measurements. The dimensioning of very small objects such as vehicles has not been tested. Assumptions involved here include: a known flying height and camera depression, a reasonably level flight (or a visible horizon), and no bizarre disturbances caused by mountainous topography. The task itself on a well-designed computer driven work station is not difficult, as proven by the successful session logs of dozens of inexperienced undergraduate students using this software at James Madison University.

The measuring of target coordinates based on known points on the ground has also proven to be meaningful on LOROP imagery. We achieved an accuracy of ±3m per coordinate using "error-free" ground truth. This converts to a relative accuracy of 0.01 to 0.02% of the stand-off distance. The success of any particular measurement task is sensitive to the identifiability of the individual ground control points. Because the target is far away, maybe blocked by intervening topographic or man-made features, and also may be fuzzy, not all control points will be equally easily identified and used. A good procedure here is to build a catalogue of control point descriptions and diagrams, so that persons other than the one who chose the point can easily understand its exact location.

Our experiments were based on only a few images; in general they have indicated that an experienced photo interpreter can expect to locate the ground position of a target on LOROP imagery to within 1 part in 10,000. At stand-off distances of 130 km, the error was found to be ±13 m. Details of the results depend on conditions. Assumptions here include the following: a knowledge of the nominal flying height and depression angle (as starting point for the software iterations), sufficient number of known ground points to guarantee a reasonable distribution of at least four to five points over the format, and reasonable accuracy in the ground control coordinates themselves. If these conditions are not fulfilled, the penalty is not failure, but simply reduced reliability for the ground coordinates of the target.

In conclusion, there can be little doubt that LOROP imagery lends iself to quantitative analysis, despite the fact that this was not generally one of the goals in the design of these sensors. This applies to both the sector scan panoramic camera as well as to frame cameras. One such matter which would help in mensuration would be the avoidance of vignetting, which may cause the loss of one or more fiducial marks. A second helpful item would be the automatic data annotation (ADAS) display of radar altitude and roll-corrected camera depression. Finally, the well-equipped photo interpreter would like to have a calibrated focal length, rather than a sort of generic number such as sixty-six inches.

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