

The Application of Real-Time and Near Real-Time  
Photogrammetry in Industry:  
A Test of Accuracy

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#### ABSTRACT

Test design and results for a photogrammetric measurement using a digital camera and automated image measurement are discussed. The tests simulate expected real-time and near real-time photogrammetric system accuracies. Internal photogrammetric precision achieved was close to 1 um RMS or 1/20th of a camera array pixel. Object space coordinates approached proportional accuracy levels of 1 part in 20,000 (coordinate error versus major object dimension).

#### INTRODUCTION

In the past few years, close-range photogrammetry has become more widely used in industry as a precise, three-dimensional measurement tool. There are now several industrial installations of complete photogrammetric systems which allow in-house capabilities for use of this technology (Fraser, 1988). As the popularity and basic recognition of photogrammetry grows, the inevitable questions of what more can be done have come quickly. These questions include: 'what can we measure that couldn't be measured in the past?' and, of course, 'what ways can the technology be improved?' Photogrammetrists and non-photogrammetrists alike now see many new possibilities for current and future photogrammetric technologies.

This paper discusses a test of an emerging technology, real-time and near real-time photogrammetry. Of particular interest is the potential accuracy obtainable from this technology. The test discussed here concerns itself particularly with precision and, most importantly, object space accuracy. The method used to complete the test is neither real-time nor even near real-time, but it does allow the accuracy potential of using a digital camera and automated target recognition to be evaluated.

As technology has advanced in all disciplines, measurement accuracy requirements in industry have generally become more stringent. It is not uncommon to have specifications that are at least 1 part in 100,000 of the major dimension of the object, and more and more often far in excess of that, approaching 1 part in 500,000 (Fraser & Brown, 1986). In spite of this need for accuracy, there is another aspect of the measurement process which is often of much more importance. That aspect is time. Half the accuracy in half the time may be a better overall solution. In fact, a real-time or near

real-time solution with an accuracy level of 1 part in 50,000 to 1 part in 80,000 would find immediate application if the technology existed today. The test described in this paper is one of an ongoing series and the results presented are the latest available at the time of writing (early 1988).

#### TEST DESCRIPTION

The photogrammetric method requires three primary steps. The first step is the data acquisition. The tests conducted used a solid-state video camera, the Sony Miniature CCD (Charge Coupled Device) Video Camera Module, Model XC-37 (Figure 1). The pick-up device for the XC-37 is an interline transfer CCD chip containing a 384 (H) x 491 (V) pixel array. The sensing area is 8.8 mm x 6.6 mm with an individual pixel size of 23 um (H) x 13.4 um (V) (Gruen, 1988). The output for the camera is a standard RS-170 analog signal so D/A conversion is built into the camera module. The lens used for the tests conducted was of 8.5 mm focal length.

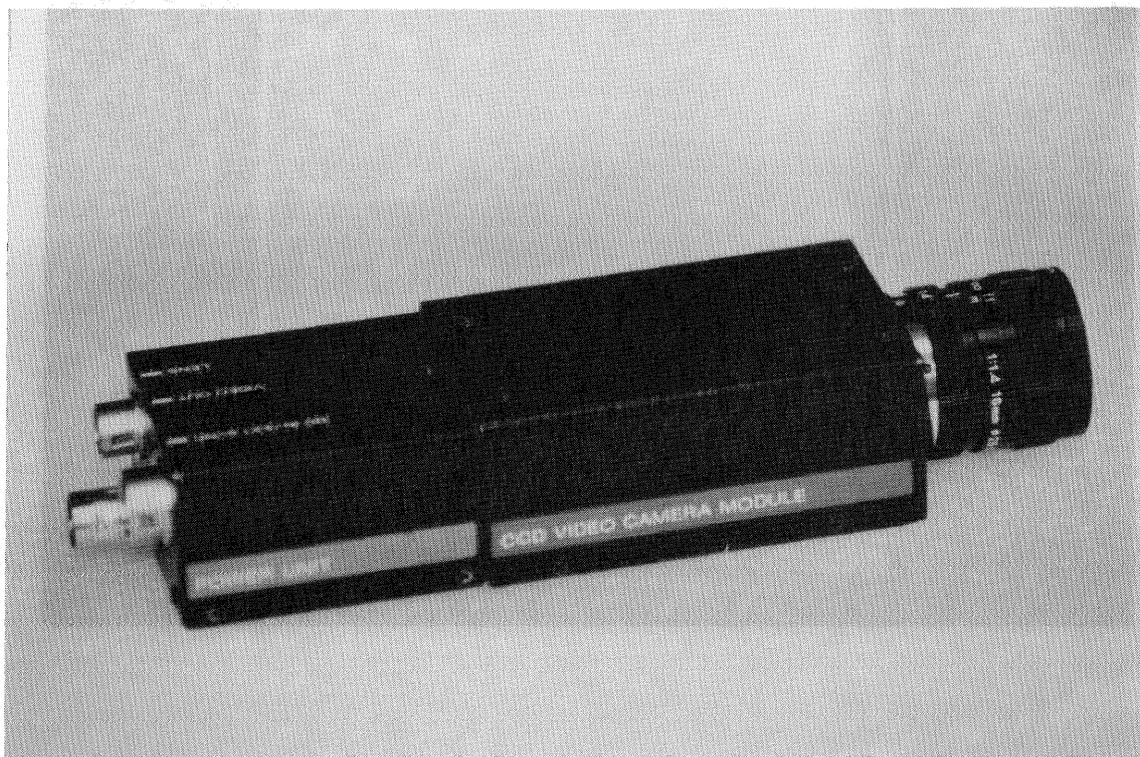


Figure 1 - Sony CCD Video Camera Module XC-37  
with Power Supply Module Attached.

The second step is image measurement. For the test, a hardware and software combination was used to automate target measurement from a digital representation of the image. To this end, the RS-170 image is transferred to an image processing board interfaced with a computer. The image is put through an A/D conversion and stored digitally in image RAM (Random Access Memory) by transferring data to a Datacube IVG-128 image processing board mounted in a personal computer. The image as captured by the IVG-128 is also displayed in real time via a small 6" RCA monitor connected to the IVG-128 (Figure 2). Actual target recognition is completed through software written for the PC in FORTRAN and Assembly Language to interface to the memory on the IVG-128. The camera and monitors described produce black and white images. Target measurements are obtained using a simple weighted centroiding of a target image with a range of grey levels.

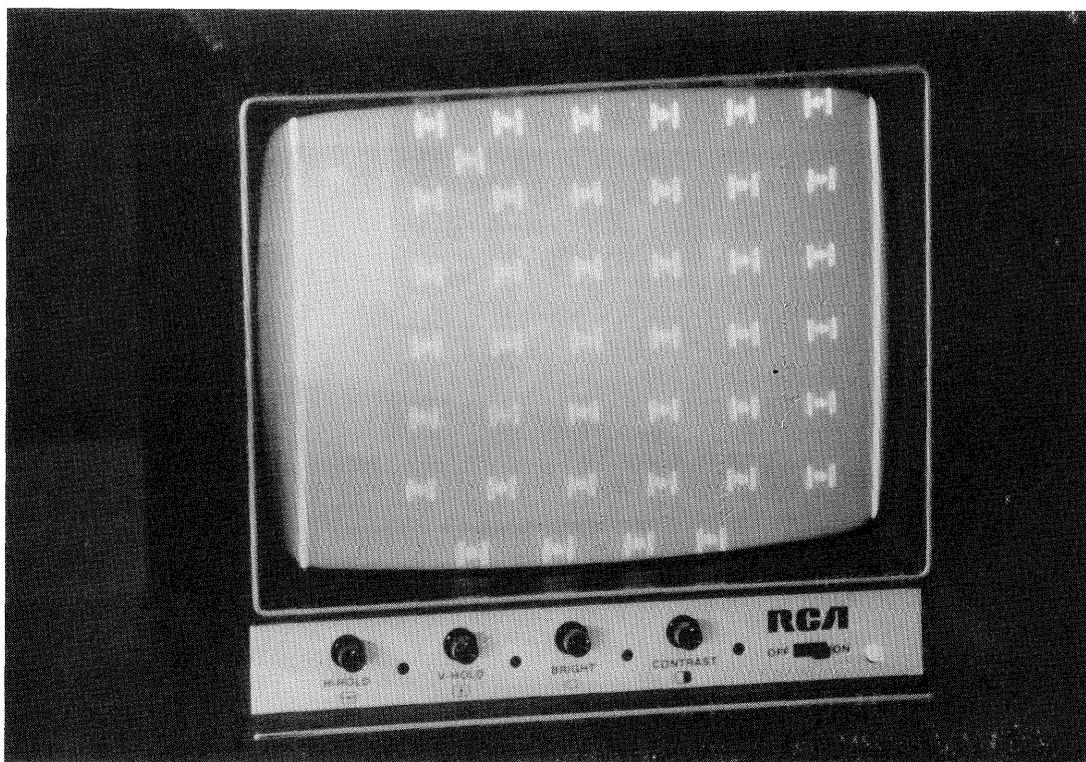


Figure 2 - Real-time display of digital image stored in image memory.

The third step is the data reduction. Data reduction and data analysis for the test were done using the GSI STARS photogrammetric system software package, including a full self-calibrating bundle adjustment (Fraser & Brown, 1986).

The network was designed to include a target array (Figure 3) approximately 1 meter square. Retroreflective targets of 11 mm diameter were placed on a 13 mm thick piece of aluminum which had been painted flat black. The selected imaging distance was 1.65 m giving rise to an imaging scale of approximately 1:200. The image size of the circular targets was about 60  $\mu$ m which constitutes 9-15 pixels in area.

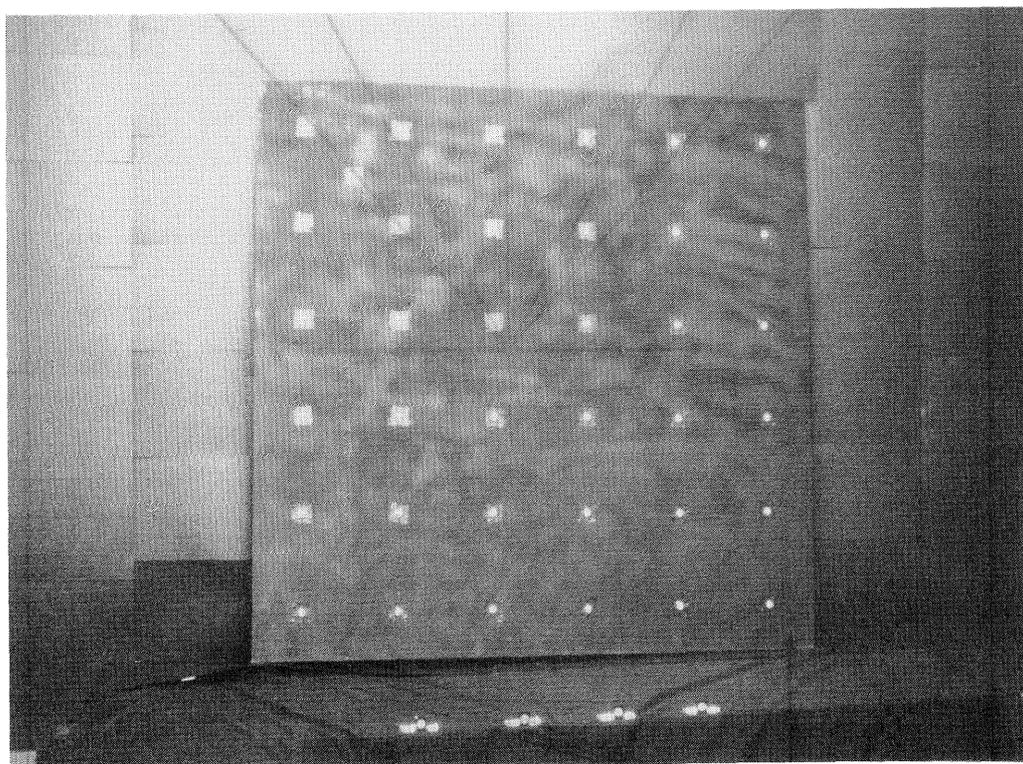


Figure 3 - The Adopted Target Array

Thirty-seven targets were placed in a grid pattern on the aluminum while four more targets were placed approximately 200 mm "above" the plane of the aluminum. The position of these 41 points was accurately calibrated using the STARS photogrammetric system to an accuracy of better than 0.01 mm (some ten times better than the accuracy anticipated from the digital camera test).

The CCD network design was basically 10 stations at each of which two images were obtained with orthogonal roll angles to strengthen self-calibration. A plan and side view of the network are shown in Figure 4. All 41 points were seen in all 20 images.

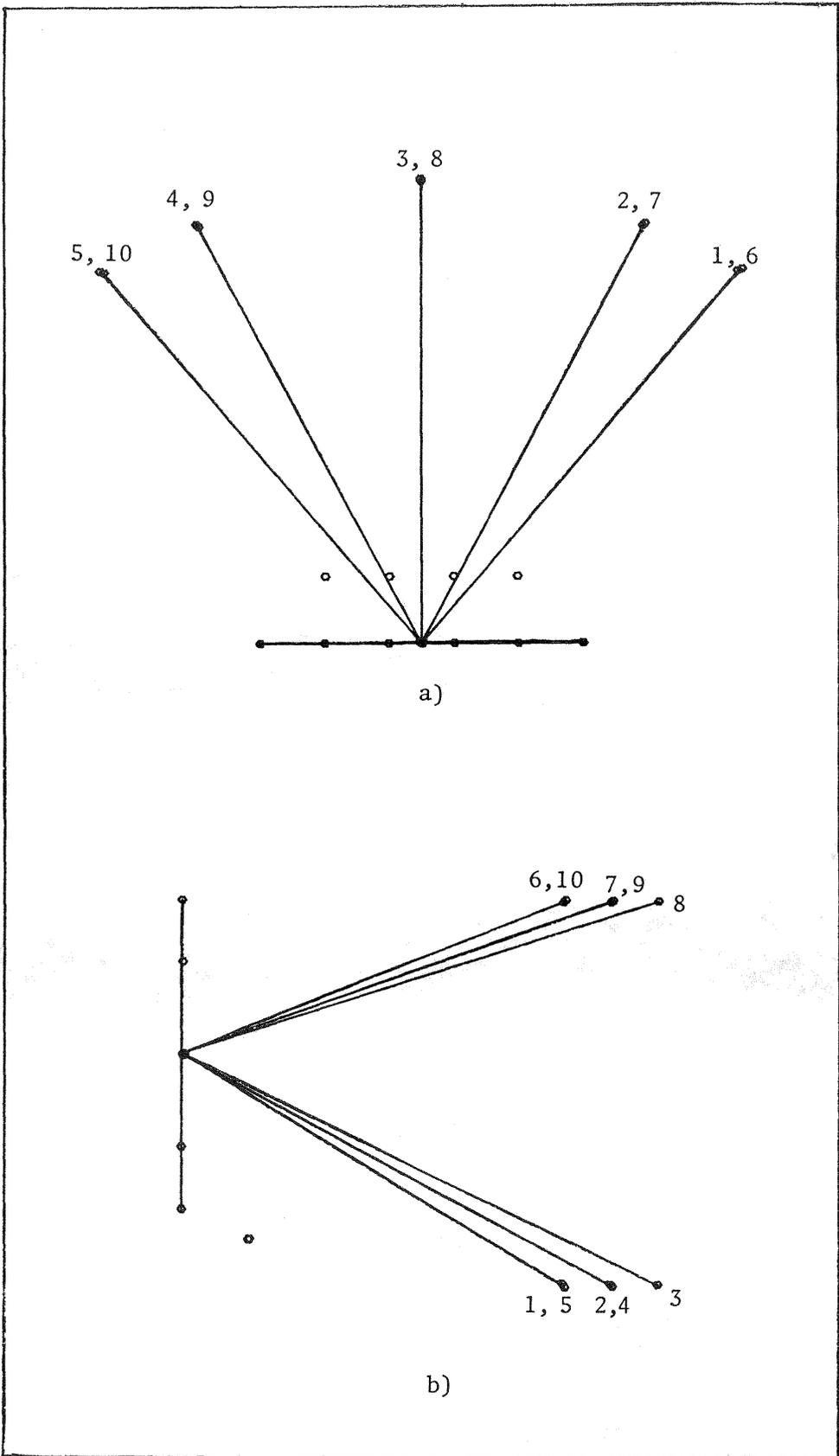


Figure 4 - The Adopted Network Geometry -  
 a) plan view and b) side view.

## TEST RESULTS

A summary of the results described below can be found in Table 1. Results are summarized using several values for comparisons.

The first results listed are those for the field calibration using the STARS system. Object space accuracies of better than 7  $\mu\text{m}$  on the XYZ coordinates (1 part in 210,000 of the major dimension of the object) were obtained. Closures of triangulation of approximately 0.7  $\mu\text{m}$  (angular accuracy of  $<0.5''$ ) were achieved with well over 500 degrees of freedom in the reduction.

In addition to the field calibration results, two types of test results are listed. Both types are for the same set of data and only show results varying because of changes in the data reduction, specifically differences in the additional parameters (AP's) for the error model.

The first results for the digital tests are for a reduction using a conventional physical error model including principal distance ( $c$ ), offset of the principal point ( $x_p, y_p$ ), radial distortion ( $K_1$ ), and decentering distortion ( $P_1, P_2$ ) (Brown, 1980). Results for the 20 image, 41 point network (as depicted in Figure 4) show predicted object space accuracies of approximately 73  $\mu\text{m}$  on the XYZ coordinates (1 part in 19,000 of the major dimension of the object). Closures of triangulation were approximately 1.1  $\mu\text{m}$  (equivalent angular accuracy of  $27''$ ) with over 1300 degrees of freedom in the reduction. Results from three-dimensional rigid body transformations with the much more precise field calibration, show levels of accuracy in the range of 81  $\mu\text{m}$  (RMS, 1 sigma), which represents a proportional accuracy of 1 part in 17,800. It should be noted that this level of accuracy is much better than any other test reported to date (Gruen, 1987).

The second results used a different camera model suggested both by CCD camera characteristics and by results obtained by others (Beyer, 1987). A characteristic of the CCD array is that both horizontal and vertical timing synchronization drive the scanning of the array. Errors in this synchronization, most particularly in the horizontal versus the vertical, have led to the expectation of an affinity in the resulting xy data (Luhman, 1987). In order to account for this affinity, and the possibility of a non-orthogonality effect, two terms were added to the previously described AP set. These effects were formulated as  $\Delta x = a_1 x + a_2 y$  where  $a_1$  shows the affinity and  $a_2$  the non-orthogonality. The data resulting from this extended set of AP's is the second set of digital results. The precision and accuracy achieved were actually very similar to those from the first reduction of digital data. Further study showed that the affinity term was basically insignificant (i.e. the maximum effect on a single point would have been 0.3  $\mu\text{m}$  in image coordinate correction). The standard error on the affinity term was nearly the same level as the value itself. However, the non-orthogonality term had up to a 3.5  $\mu\text{m}$  effect and the coefficient exhibited a clear statistical significance.

TABLE 1 - Summary of Test Results

	Closures of Triangulation (RMS in $\mu\text{m}$ )			Degrees of Freedom	Object Coordinate Standard Errors (RMS in mm)			Residuals of Transformation to Field Calibration (RMS in mm)			
	x	y	Total		X	Y	Z	X	Y	Z	Total
Field Calibration	0.62	0.73	0.68	561	0.005	0.005	0.010	-----	-----	-----	-----
Test Data Set 1 - Standard AP's	1.19	1.04	1.12	1395	0.058	0.096	0.074	0.086	0.086	0.074	0.081
Test Data Set 2 - Standard AP's + 2 *	1.10	0.90	1.00	1393	0.053	0.086	0.066	0.089	0.094	0.074	0.086

\* Note - see text for description of AP's added for affinity and non-orthogonality.

Another technique for analyzing the internal photogrammetric precision of the camera system is to look at the basic network closures from the bundle reduction as compared to the effective pixel size in the camera used. The chip used has pixels of 23 um (H) x 13.4 um (V) and yielded precision of about 1/20th of a pixel (1 um in 23 um for x, 1 um in 13.4 um for y, average about 1/20). Better internal precision may be achievable using template matching or other target measurement techniques.

#### CONCLUDING REMARKS

Although the results reported above are encouraging, they are far from the expected higher accuracy which will most likely be required of a commercially successful video based photogrammetric system. Many techniques could be used to help improve accuracy including increasing target size, collecting more images and improving the basic target measurement. However, these "improvements" may lead to other problems such as the targets being larger than practical, the collection and processing of extra images would add significant time to the overall measurement process and more sophisticated target measurement techniques may also be more time consuming. When real time or near-real time results are required, small increases in processing time may be quite detrimental. Certainly the results reported prove that the CCD imaging system with a most basic target recognition can achieve reasonable levels of accuracy. As technology pushes forward, better accuracies should certainly be attainable. Advances would be expected to include the more routine production of large format CCD chips (to improve image scale, thus improving object space accuracy), that are economical and readily available.

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