A VIDEO-BASED INDUSTRIAL MEASUREMENT SYSTEM

by

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ABSTRACT

Industrial measurement applications include many tasks that are time critical. While video imaging technology provides many advantages over film-based systems with respect to speed, the levels of accuracy and repeatability attainable using a film camera far exceeds that of video. However, video imaging has progressed to a point where acceptable accuracy levels for many industrial applications are possible. This paper discusses a video-based system tested on objects of 1-2 meters or more in size, demonstrating accuracies of up to 1 part in 70,000.

1. INTRODUCTION

Modern industry has become more and more sophisticated over the years and metrology techniques and requirements have contributed greatly in this growth. As quality assurance becomes a key to market success, extensive efforts are placed on reliable techniques to confirm dimensional integrity. Metrology systems from the past decade have allowed highly accurate and reliable results at a level of productivity that has been economically attractive to the industrial end user. In fact, virtually all the large aerospace corporations in the US and many elsewhere have multiple photogrammetry, theodolite, CMM and other metrology systems. As industry becomes familiar with the current technologies, they are able to appreciate the advantages, and also realize the shortcomings, of many measurement techniques.

Film-based photogrammetric systems have shown several advantages for many different types of measurements. Some of these advantages include high accuracies, a large number of points measurable in a practical manner, objects in a wide variety of sizes possible with the same system and many others (Fraser & Brown, 1986; Fraser, 1992). Another of the advantages is the speed of the overall measurement and most particularly, of the data acquisition (quick photography resulting in reduced down time, etc.). However, the overall speed can also be a shortcoming for certain types of applications. Building or adjusting objects is often a task more suited to theodolite-based systems. Higher productivity and throughput would make photogrammetry even more widely applicable.

Video-based photogrammetric systems are focused on the need for higher overall speed of measurement, most obviously gained through the deletion of the film developing phase of the project. Automation of image measurement has improved in film-based systems as far as speed and reliability (Brown, 1987) but the potentials in video are for far greater speeds. Thus far, video-based systems have not gained general acceptance in industry. One of the main reasons for this has been the need for greater accuracies than those available using video techniques. While productivity is an advantage, a major part of the modern manufacturing and quality assurance processes require strict levels of accuracy. As video technology has improved, the accuracies possible with video-based systems have improved to a level that is acceptable for many applications.

The studies discussed in this paper concentrate on the potentials of some higher end video equipment in terms of accuracy and repeatability. Three separate test scenarios are discussed with points of interest from each highlighted. The first test involves a calibrated test field with a modest number of images measured several times. The second test simulates a full scale antenna survey using a particular convenient geometry. The final test returns to the test field approach but uses significantly more images per network.

2. TEST HARDWARE

The primary system tested includes a video camera, image processing boards and computer. The video camera used in this study is the VIDEK MEGAPLUS camera . The VIDEK features a CCD sensor of Class 1 (virtually defect free) with a 1340 H x 1037 V array of pixels. The first and last rows of pixels as well as the first 20 columns of pixels are shielded from light and serve as dark level reference to reduce the effects of dark current. The remaining light sensitive area of the array is 1320 H x 1035 V pixels and measures 8.98mm H x 7.04mm V. These pixels are 6.8 µm square and are evenly spaced horizontally and vertically. Video information is digitized to 256 grey levels by the camera's built in A/D converter. A full frame of video information is 1.3Mbytes in size and is transferred in 144.5 ms. Output video is in both analog and digital format. Digital data is sent as an EIA compatible 8 bit parallel signal . The analog output is a non-composite, 1volt peak-peak signal transmittable on a 70 ohm impedance line.

The lens used is a variable focus 20mm Nikon with a field of view approximately 20 by 25 degrees. The aperture is set manually with a range of f2.8 to f22. The shutter is an electronically actuated mechanical blade with variable exposure timing (1/100 sec to 1/4 sec or longer in certain circumstances). Roll capability was added via a modified CRC-1 roll ring (see Figure 1)

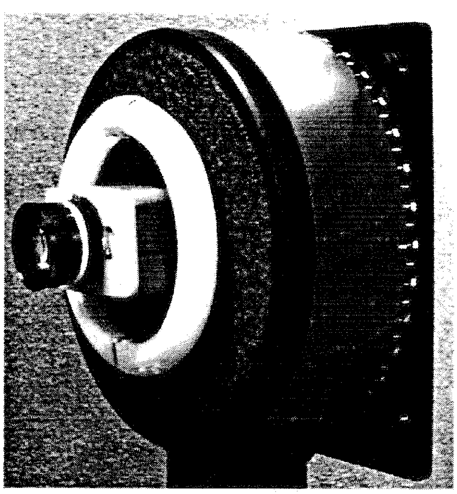

Figure 1
Videk Shown in CRC-1 Roll Ring

The image processing boards used are the Imagraph HI*DEF system. The system consists of three boards: A High Definition Frame Buffer (HDFB), a High Definition Frame Grabber (HDFG) and an Analog Processing Module (APM). The system also includes the HI*DEF software library. These routines provide the basic software interface to the HI*DEF boards.

The HDFB is a high resolution graphics controller and frame buffer that displays images in 8 bit planes (256 shades). Images are displayed at a resolution of 1280 H by 1024 V. Also provided are 2 bit planes of overlay memory that can be displayed at ¼ resolution (320 H by 1024 V). Video output is RS-343 RGB at a 60 Hz refresh rate.

The HDFG is a digital frame grabber that can handle 8 or 12 bits of TTL digital video input. The frame grabber has 1.28 Mbytes of frame buffer memory. It also has 6K of input LUT memory.

The APM is a daughter board to the HDFG and can handle a variety of analog video signals. Analog input is digitized to 256 grey levels. The digital information can then be processed by the HDFG.

The HI*DEF software library consists of hardware device drivers and image processing utilities specific to the Imagragh boards. The libraries are written and designed for use with MicroSoft C, version 5.1.

The HI*DEF boards are installed in a DELL 486D/33 80486 based computer running at 33 MHz. The operating system is MS-DOS 5.0 with application code written in MicroSoft C. Video is displayed on an 18" RGB monitor manufactured by Monitronix Corp.

3. TEST NETWORKS

The studies discussed in this paper center around results from the measurements of three test fields, as discussed in the introduction. Several aspects of the test are common and are discussed here.

Targets on the test fields were high contrast images with virtually no competing noise and occupied from 50 to 150 pixels on the sensor. Targets were centroided using a weighted center of mass technique suggested by Trinder (1989):

$$
\begin{aligned}
x &= \frac{1}{M}\sum_{i=1}^{n}\sum_{j=1}^{m} j \cdot g_{ij} w_{ij} \\
y &= \frac{1}{M}\sum_{i=1}^{n}\sum_{j=1}^{m} i \cdot g_{ij} w_{ij} \qquad (1) \\
M &= \sum_{i=1}^{n}\sum_{j=1}^{m} g_{ij} w_{ij}
\end{aligned}
$$

g_{ij} is either 1 or 0; 1 if pixel$_{ij}$ is above threshold value.
w_{ij} is weight value equal to the light intensity of the pixel
i is the row position of the pixel
j is the column position of the pixel

All of the fields were calibrated using the GSI STARS photogrammetric system; in particular the CRC-2 camera, the AutoSet-2 film comparator and the STARS suite of programs centered around a rigorous self-calibration bundle adjustment program. Typically, this calibration was more than 5 times more accurate than the video-based work.

All simulations were completed using the STARS simulation software, including both the video-based and film-based measurement networks.

3.1 TEST NETWORK 1

The first test discussed took place in 1991 and was presented in Winnipeg for Commission V of ISPRS (Gustafson, 1991). It involves the video measurement of a test field and the accuracies achieved from each of two target sizes. The test field used is a 7mm thick aluminum sheet painted flat black. The targets used in this test were 6mm and 11mm diameter circular retro-reflective targets. The targets comprise a basic grid pattern and additional targets were placed on shims to offset points from the surface 10 to 25 mm. To aid in the capturing of images, the test field was placed horizontally on a turntable. Figure 2 illustrates the basic geometry used in this video test. Note a single camera was used and that the test field was rotated to obtain the geometry shown. Two rolls were taken at each position for a total of 8 stations.

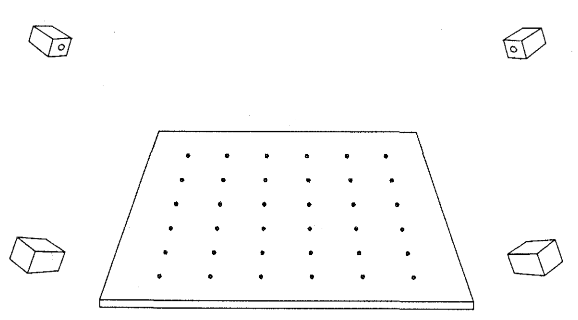

Figure 2
Test field and camera geometry

Computer simulations were made to make accuracy predictions based on two levels of image measurement precision, the equivalent of 1/20th pixel and 1/50th pixel respectively. Resulting accuracy expectations were 1 part in 30000 to 1 part in 80000 over the major dimension of the area to be measured (1.45M).

RMS Closures of Triangulation			
XY Residuals (microns)		Ratio to Pixel Size	
6mm	11mm	6mm	11mm
0.34	0.23	1/20	1/30

Table 1

Results are reported for both the 6mm and 11mm targets. The first data reported is the summary for the closures of triangulation for the bundle adjustments, an of indication internal precision (see Table 1).

The second data reported is the summary of accuracy results. Results in this case are comprised of the residuals resulting from a three-dimensional rigid-body transformation of the video results into the film results (see Table 2). The film measurement yielded accuracies on the order of 1 part in 300000 (about 0.005 mm in each axis) and had an RMS closure of **sigma**$_{xy}$=0.59**μm**.

Accuracy Summary - Videk vs. CRC-2							
6mm Targets				11mm Targets			
vX	vY	vZ	vXYZ	vX	vY	vZ	vXYZ
0.038	0.041	0.030	0.036	0.025	0.028	0.025	0.025

Table 2

A couple of points of interest should be discussed. To begin with, closures of triangulation are improved significantly with the larger target size. As mentioned previously, target images are measured using a weighted centroid technique and the more pixels involved in the computation, the better the centroid can be determined. The images for the 6mm targets range from 40 to 60 pixels in area while the 11mm targets range up to 130 pixels. Also observable is the better accuracy achieved with the larger targets. Accuracies of nearly 1 part in 60000 were obtained with the 11mm targets while 1 part in 40000 was the value for the 6mm targets.

3.2 ANTENNA MEASUREMENT

A test was carried out in early 1992 to simulate a portion of a full scale antenna survey. The final potential application of the video technology is as the measurement portion of a closed-loop shape adjustment system for a 34m reflector. The suggested scenario would place several video cameras around the edge of the reflector in a more or less permanent arrangement. As many as 24 cameras would be attached at even intervals around the edge looking across at the other side of the reflector. Retroreflective targets would been seen in at least 3 images each, with some in many more than that. Computer simulations were made to initially establish the viability of such a system. In the final system, accuracies on the order of 0.5mm would be required (about 1 part in 68,000). On an RMS basis with 1/50th of a pixel pointing precision, this level was not quite achieved and in the case of the maximums, estimated accuracies were 3 times the required level. A notable exception was in the axis aligned with the axis of the reflector. This axis, which is the most important, had estimated accuracies which all were within the requirements, even the maximums. By virtue of these results, it was deemed appropriate to investigate further.

A full reflector survey was not practical initially so a simulation of a portion of the reflector was suggested. A 3 camera segment of the 24 camera network observing a triangular "petal" of the reflector was simulated (see Figure 3). Because the 3 station network is not as strong as the 24 station network, the expected results were not as favorable. As long as they were predictable, this situation was acceptable. For this reduced network,

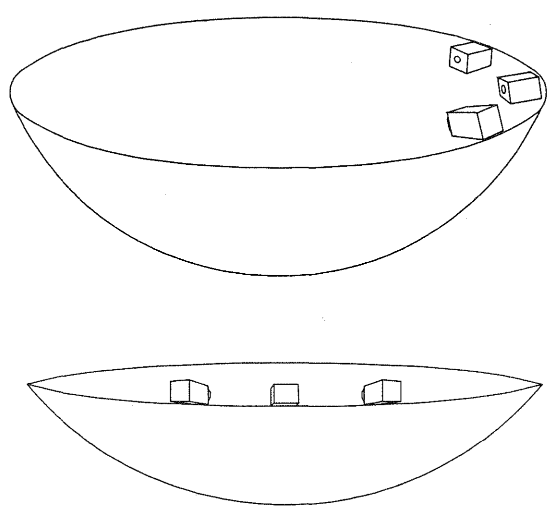

Figure 3
3 Camera Station Geometry

computer simulations predicted accuracies 3 to 4 times worse, especially in the axial direction of the reflector.

In order to simulate this measurement in a more practical and timely manner, in preparation for a measurement on the actual dish, a 1/4 scale version of the network was created at GSI in Florida. This scaled version was to serve as a proof of concept. The 1/4 scaling was applied to the size of the object, the size of the targets, the positioning of the camera, and the expectations for accuracy. For this test, a single video camera was used and moved into the three positions required. The simulated object was very stable (concrete), so no deformation was experienced during data acquisition. Targets of about 12mm were used, resulting in images containing approximately 50 - 100 pixels. Concurrent to the collection of video information, a film-based network was taken using a CRC-2 to calibrate the target field. This allowed a check of the actual accuracy of the video-based measurement as the film-based results were more than 5 times more precise.
A summary of the predicted and actual errors for the video measurements are listed in Table3 below.

Summery of Accuracy Estimates (mm)						
	Simulated			Actual		
	X mm	Ymm	Z mm	X mm	Y mm	Z mm
RMS is	0.203	0.163	0.097	0.465	0.381	0.208
Minimum is	0.091	0.025	0.076	0.211	0.061	0.165
Maximum is	0.391	0.264	0.119	0.914	0.648	0.254

Table 3

The computer simulation assumed measurement precision of 1/50th of a pixel and only about 1/25th was achieved, thus the difference in estimated accuracies. This is most likely because of possible unresolved systematic errors in pointing precision and possible instabilities in the lens elements.

The film-based measurement had an actual RMS accuracy estimate of about 0.075mm in plane, and 0.038mm out of plane. The comparison of the video-based data and the film-based results are listed in Table 4 below.

Transformation results Video vs. Film (mm)		
vX	Vy	Vz
0.434	0.234	0.198

Table 4

These results are consistent with the actual estimated accuracies. As a result of this test, it is expected that mid-1992 a test using 3 separate video cameras on the actual reflector will be carried out by GSI.

3.3 TEST NETWORK 3

The third test took place in 1992 and the test field is essentially the same as used in TEST NETWORK 1 (see Figure 4). In this new version the grid of targets was replaced by "fresh" 12.7mm retro dots and the vertical offset targets now occupy points on the grid. There are no 6mm targets placed on the new field as the larger targets produce superior results . Six targets were offset from the plane by 10mm to 25mm shims. Two eight station film-based calibration networks were taken of the test field; one before, and one immediately after the video portion of the test.

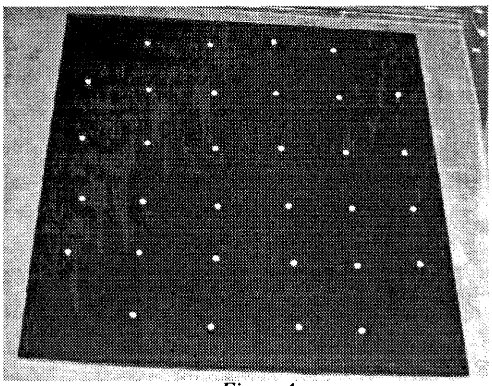

Figure4
Re-furbished Test Field

A set of 120 video images was collected and measured for this test. The 120 images were taken in two steps . The first 60 images were collected by setting the camera roll to 0° and by rotating the test field in 6° increments on its rotating base. Similarly, the second set of 60 images were collected with a camera roll of 180°. Data analysis was performed using 8, 16, 30, 60 and 120 station network sets of the collected data. Target images occupied approximately 100-150 pixels on the sensor.

Target images were driven to automatically using a curve prediction algorithm. This required an operator to initially identify targets on three frames by using a pointing device and a graphics monitor. The remaining frames were measured automatically at a rate of about 15 seconds per frame (including rotating the test field). No prior knowledge of the object was required.

The results are divided into two sections. The first set of results is from five different combinations of runs from the set of 120 images measured. Analysis was performed on 8, 16, 30, 60 & 120 station sets of this data. The second set of results is a repeatability test composed of portion of the 120 image set broken into eight independent networks of 8 stations each.

Closures Results for Videk Camera (microns)				
# of Stations	s_x	s_y	s_{xy}	Ratio to pixel Size
8	.28	.25	.27	1/25
16	.28	.25	.27	1/25
30	.28	.23	.26	1/26
60	.23	.19	.21	1/32
120	.27	.23	.25	1/27

Table 5

The first set of results from this section is the RMS of closures for the bundle adjustments for each of the run combinations (Table 5).

Although these closures are consistent with previous measurements of target images of approximately 150 pixels, pointing precision on the order of 1/50 pixel or better for images of this size is expected. However the thresholding technique suggested by (Trinder 1989) has not yet been incorporated in the measurement process. This may explain some systematic effects in the results. For 256 grey levels Trinder suggests:

$$T=74.(SF)^{1.3}A^{-1}$$

where SF refers to the 2-sigma-width Gaussian spread function and A the target size

The second set of results is the estimated and actual accuracy summary for each combination of runs (Table 6).

Estimated and Actual Accuracies for Five Combinations of Runs (mm)		
	Estimated	Actual
# of Stations	vXYZ	vXYZ
8	0.025	0.023
16	0.017	0.018
30	0.011	0.017
60	0.008	0.016
120	0.006	0.018

Table 6

As expected, the accuracy estimates improve proportional to the square root of the number of stations. The actual accuracies, however, show no significant improvement after 16 stations. This is not what would be expected if the errors in the measurement were predominately random. It is therefore believed that unmodeled systematic error remain in the data. Figure 5 shows a graph of both estimated and actual accuracies as a function of the number of stations. Also shown is the theoretical curve of accuracy improvement.

The graph does illustrate to a certain level that the addition of multiple stations improves accuracy. In this case accuracies improved from 1:50,000 in the 8 Station set to accuracies in excess of 1:70,000.

The second section of this test is a repeatability test made by separating the 120 video images into eight independent data sets. Each of the data sets was reduced

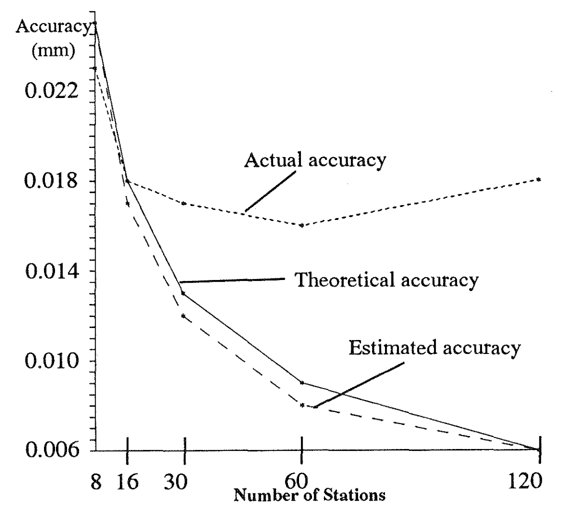

Figure 5

Graph of Accuracy vs. # of Stations

as before and the results reported are the closures of triangulation (Table 7) and the estimated and actual accuracies (Table 8). Actual accuracies are determined from the RMS residuals of a three dimensional coordinate transformation into the film-based measurements.

The accuracy results achieved are actually quite good. The range of relative precision is from 1:36,000 to 1:51,000 of the major dimension of the object with these

Closures for Each of Eight - 8 Station Runs				
Test #	s_x	s_y	s_{xy}	Ratio to pixel Size
1	.28	.25	.27	1/25
2	.22	.20	.21	1/32
3	.28	.23	.26	1/26
4	.25	.20	.23	1/30
5	.27	.19	.23	1/30
6	.24	.22	.23	1/30
7	.23	.21	.22	1/31
8	.22	.21	.22	1/31

Table 7

Estimated and Actual accuracies for Each of Eight - 8 Station Tests		
	Estimated	Actual
Test #	VXYZ	VXYZ
1	0.025	0.023
2	0.025	0.033
3	0.022	0.023
4	0.021	0.031
5	0.025	0.023
6	0.025	0.033
7	0.022	0.023
8	0.021	0.031

Table 8

8 station versions. However, as seen from the previous section there is a considerable advantage to the measurement of multiple images. This advantage is expected to improve significantly when suspected unknown systematic errors are traced and properly modeled.

4. CONCLUDING REMARKS

Specific problems still lie in the stability of the lens for the video camera tested (Gustafson. 1991). After isolating the lens from the strobe, lens element movement is still noticeable. At the time of the submittal , another lens had not yet been tested to confirm whether the problems were from a single lens or from the lens type which may be the source of the systematic errors discussed in 3.3. Additionally, many of the results suggest that there may be cases wherein models typically used to correct for systematic effects in most film cameras do not completely model systematic effects in the video camera used. As pointed out previously, there is also an expectation of improvement using improved thresholding techniques.

The general trend of the results discussed is good. Accuracies at the level of use in industrial environment have been obtained and confirmed (up to 1 part in 70,000). There certainly appears to be room to improve but with the results obtained to date, studies will continue.

Acknowledgments

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