Test of Photogrammetric Accuracy for Mensuration of Aerospace Tooling

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ABSTRACT

In recent years, Photogrammetric principles have been applied in many areas of industrial mensuration. However, questions still arise concerning overall accuracies that can be achieved by photogrammetry, the choice of cameras and photogrammetric instrumentation. This paper will discuss a photogrammetric benchmark test that was undertaken to evaluate overall photogrammetric accuracies and evaluation of automatic target readers and photogrammetric cameras.

INTRODUCTION

Within the last decade most major aerospace manufactures in the United States have initiated studies in areas of photogrammetric applications. Although there are numerous and potential applications for photogrammetry, it has been mainly used in the area of periodic tool inspection of aircraft assembly tools. Aerospace companies have adopted various photogrammetric instruments and procedures, which in turn provide different degrees of accuracy. Reported accuracy for a two photo stereo approach has been in the realm of .380 mm to .508 mm. This is unacceptable for periodic tool inspection. Other methods such as convergent photography using monocomparators and analytical plotters report accuracies in the realm of .127 mm to .254 mm. Systems utilizing automatic scanning and target reading have reported accuracies of .025 mm to .051 mm. Since there has been noticeable differences between various measuring systems there was considerable interest to undertake a benchmark test.

During the summer of 1985 General Dynamics, Fort Worth(GDFW) division, conducted a bench-mark test to evaluate Photogrammetric systems including the Pass 2000 system (Photogrammetric Automatic Scanning System).

BACKGROUND

In recent years growing interest has been expressed in the need for obtaining fast, accurate, and reliable close range photogrammetric measurements of scientific and engineering structures.

Existing photogrammetric hardware, including the new 2nd generation analytical photogrammetric plotters, are designed primarily for aerial mapping applications with software changes for close range photogrammetry. These instruments require a skilled operator who must estimate where the center of a targeted point is in order to measure it. These systems are restricted in the type of images which can be measured and possess no capability for image enhancement.

In 1982 Northrop Corporation, Aircraft Division, decided that classical manual photogrammetry presented several problems such as operator skill level and lost time due to poor readings and blunders. They understood the demands engineers face for implementing systems that require fewer man hours to operate and at a lower skill level. Only an automated system could meet these demands.

In 1983 Northrop Corporation became the first company to implement an automated photogrammetric system for use in aircraft tool inspection. The instrument was a Perkin-Elmer Microdensitometer utilizing a PMT (photomultiplier tube) as a detector. It was also equipped with peripheral computers and a R.P.I. photogrammetric software package, including software for automatic centroid determination from photographic images.

The success of the original PASS system led to the development of the new Pass2000 system, through a joint effort by Perkin-Elmer Corp. and R.P.I.. The system has the capabilities for a multi role environment.

PASS 2000

The PASS 2000 consists of several computer components and peripheral devices, as well as a precision X-Y stage assembly, which are combined into a system for photogrammetric mensuration which has machine vision capabilities. In short, the system may be considered as an interactive robotic monocomparator.(Robertson,Wyatt 1984)

The system incorporates two detector assemblies: a CCD camera and a PMT. The detector heads can be interchanged within minutes.

Control Computers

The PASS 2000 system can be configured in two ways, low or high speed thruput. The system can operate using a Digital PDP 11 series computer as a host. For high thruput a Digital PDP 11/73 is used with a MicroVax as a host. The Micro-D and image processor utilize their own processors.

There are several reasons for using multi-processing:

1) Speed: Communication between the various processors free the system for data reduction.

2) Software: Software modules are easily maintained or updated without affecting other units of the system.

3) Efficiency: The system is truly multi-tasking. Several data reduction or bundle programs can be running in the computer, graphic plots or image processing can be accomplished without affecting thruput in the scanning procedure. There are no compromises due to computer memory or speed limitations. In the data reduction operation every approximation can be considered and run on the system.

The PASS 2000 computer hierarchy allows each processor to work independently of each other. For example, if the PMT head were used to scan images, the processor in the Micro-D can independently transfer data directly to tape without interfering with the PDP 11/73 or MicroVax. The PDP 11/73 can act as a host computer and controls the PASS 2000 system without the MicroVax computer, or the MicroVax can be used as the host without the PDP 11/73.

The standard peripheral components consist of a console terminal with graphic capabilities, work station, video monitor, digitizer tablet, and function control unit. (Figure 1)

PASS 2000 System Software

The following represents the major software modules.

- o Automated calibration routine.
- o Photogrammetric simulation package.
- o Image processing and target analysis.
- o Photogrammetric processing and control.
- o Bundle adjustment program.
- o Graphics module.

Photographic Input

- o Any photographic format from 8mm to 20" square can be analyzed on the PASS 2000.
- o X-ray and Ultrasound images can be enhanced and measured
- o Any type of photographic medium can be used from any camera.
- o Manual and computer-controlled film transports are available.

The PASS 2000 offers powerful image processing and computer capability that can be applied to real time photogrammetric techniques (Robertson,1986)

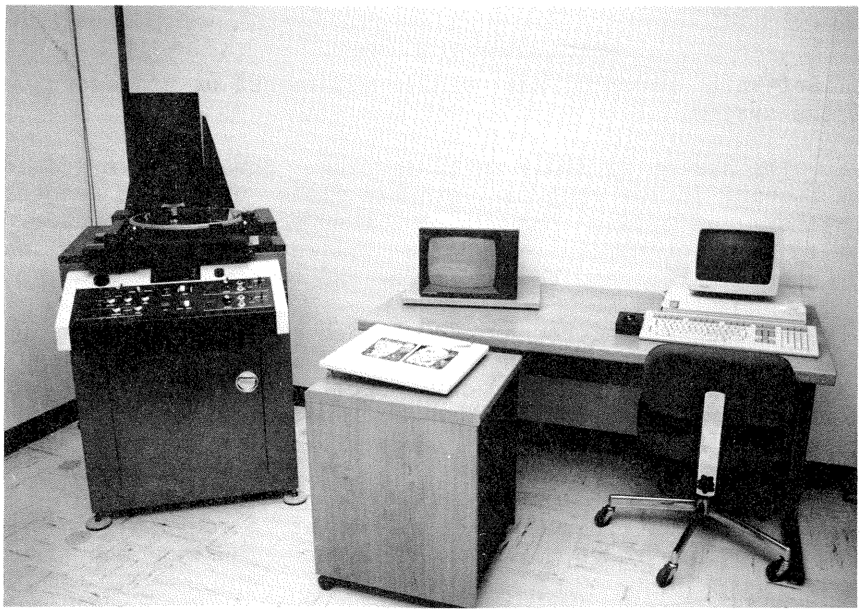

Figure 1. PASS 2000 SYSTEM

DESCRIPTION OF TEST

Two fixtures were to be photographed and measured. One was to demonstrate the system accuracy. The second to simulate a periodic inspection of aircraft tooling. Two sessions of photography and measurement were to be undertaken for each fixture.

Guidelines for the test were as follows:

1) Prior to arrival at GDFW facility, a computer simulation of both fixtures, showing camera station locations and expected accuracies were to be completed from nominal dimensions supplied by GDFW.

2) Only retro-reflective targets were to be used

3) Any choice of camera could be used for the photography.

4) Two photogrammetric surveys were to be undertaken for each fixture. Prior to the second photographic session, and without the presence of the our photogrammetric team, a number of target locators were to be offset by an undisclosed amount.

5) The target locations that were offset by GDFW and the amount of the offset were not to be provided during the data reduction.

6) All photography and processing was to be completed in one working day.

For the accuracy test a metal surface plate (MSP) of approximately 1.8X 4.5 m was established with a high quality control network. The test to simulate the accuracies for periodic inspection of aircraft tooling was a full scale development (FSD) wing tool.(Figures 2 and 3)

Photography

The photography was accomplished using a Zeiss Jena U.M.K.10 camera owned by GDFW. To show the full capability of the PASS 2000 system, subsequent photographs were taken of the MSP fixture using a standard 35mm Olympus camera (fl=50 mm) and a semi-metric Rollei Reseau camera (fl=80 mm) with a 6X6 cm format. For the U.M.K. photography Kodak Select flat glass plates of 3.3 mm thickness were used. For the 35 mm and 6X6 cm photography Kodak Tri-X pan film rated at 400 ASA and Kodak Tech Pan film rated at ASA 200 and 25 respectively were used.

TEST RESULTS

MSP Fixture Analysis

For the analysis of the MSP fixture six photographs were taken during the pre and post photographic sessions. The photo scale was approximately 1:32. GDFW provided XYZ coordinate values for three control targets with an accuracy of .051 mm for XY and .023 mm for the Z coordinate. The values of the shims used for the target offsets were known to be accurate to .003 mm.

During the measurement phase all target locators were automatically measured utilizing the CCD detector. For the data reduction phase an arbitrarily assumed datum was used. The XYZ coordinates were then transformed to GDFW datum through a three-dimensional similarity transformation. The Z coordinates between the pre and post data reduction that were not offset by GDFW had a RMS value of .013 mm with a standard error of .003 mm. The locators that were offset between the pre and post sessions had a RMS value of .018 mm with a standard error of .005 mm. (Table 1).

For the 35mm and the Rollei photography using Tri-X pan film the retro-targets were suppressed (flash disconnected). This was to illustrate the capabilities of the system to measure targets under available light and less than ideal conditions. The RMS value for the 35mm data was .191 mm and the Rollei .094 mm. The 35mm and the Rollei data sets obtained from Tech-Pan film had a RMS value of .109 mm and .056 mm respectively. This increase in accuracy is due to the stability of the Tech-Pan film and to well defined targets. It should be noted that not all the Rollei Reseaus were read during the retro target test.

In addition to the above testing, the U.M.K. plates of the MSP fixture were measured on a Kern monocomparator. All the data was reduced in the same manner as the original readings. The overall accuracies of the monocomparator, although good were less than 75 percent of the overall accuracies obtained from the PASS 2000 system.

FSD Fixture Analysis

The analysis of the FSD fixture was similar to the MSP fixture. Six photographs were taken for both the pre and post sessions. The photo scale was approximately 1:32. GDFW had provided XYZ coordinate values for six target locators that were known to .127 mm for XYZ. Since this was a simulation of a periodic tool inspection we used GDFW control values. The RMS value for the Z coordinates were .152 mm. An arbitrarily assumed datum was then selected and the pre and post data sets were analyzed independently. The RMS value for the Z coordinate was .033 mm (Table 2)

TABLE 1

Data in mm

Target	Z displacement between pre and post actual (GDFW)	Measured Z displacement UMK data pre and post	Diff.
4	1.212	1.204	-.008
5	.808	.808	.000
8	.808	.767	-.041
10	.808	.803	-.005
12	1.615	1.615	.000
13	1.615	1.620	.005
14	.404	.391	-.013
15	.808	.788	-.020
20	.404	.429	.025
21	1.212	1.202	-.010

TABLE 2.

Data in mm

Target	Z displacement between pre and post actual (GDFW)	Measured Z displacement UMK data pre and post	Diff.
1	1.212	1.192	-.020
2	.404	.439	.035
8	.404	.414	.010
9	.404	.399	-.005
10	.404	.427	.023
14	1.212	1.242	.030
16	1.615	1.645	.030
20	.808	.785	-.023
21	.808	.778	-.030
25	.404	.358	-.046
26	.404	.376	-.028
30	.404	.340	-.064
33	.808	.750	-.058
34	.808	.780	-.028
37	.808	.841	.033
38	.404	.442	.038
39	.404	.447	.043
40	.404	.424	.020
41	.404	.429	.025
42	.404	.434	.030
43	1.212	1.174	-.038
44	.404	.363	-.041
45	.404	.434	.030
47	1.212	1.194	.018
50	.404	.378	.026
53	.404	.424	.020
54	1.212	1.222	.010

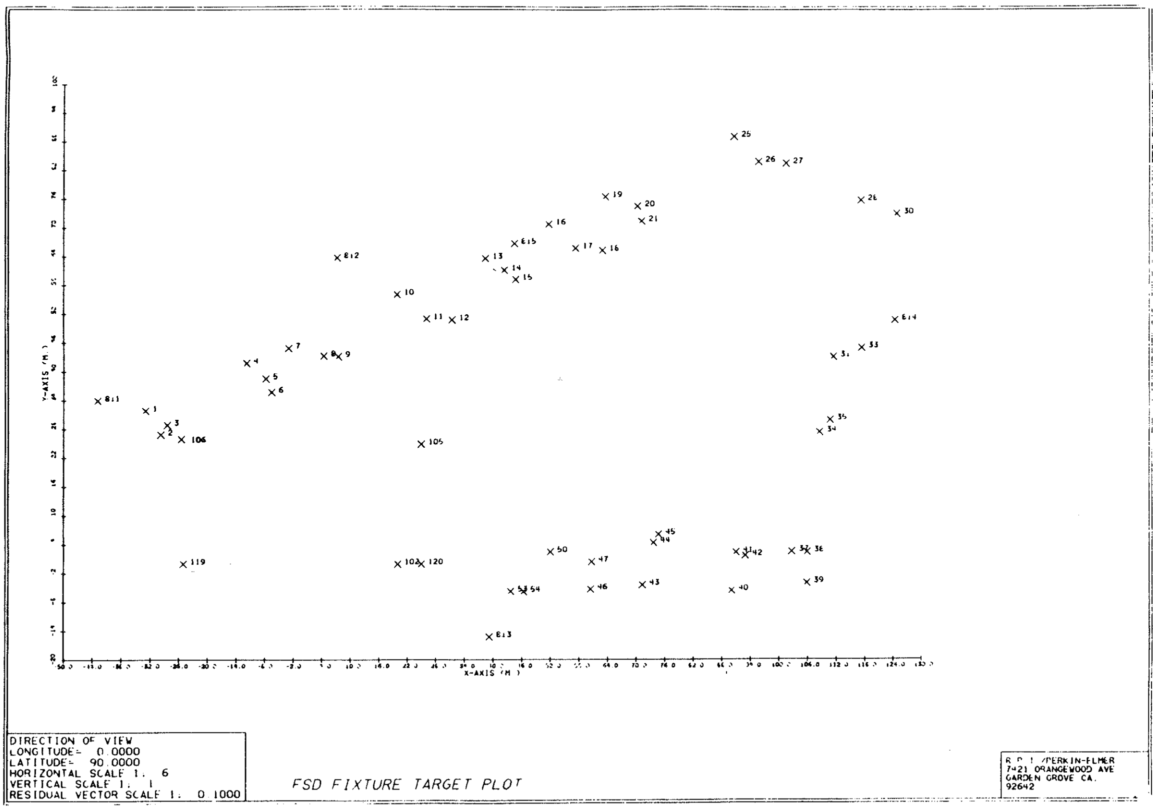

FIGURE 2

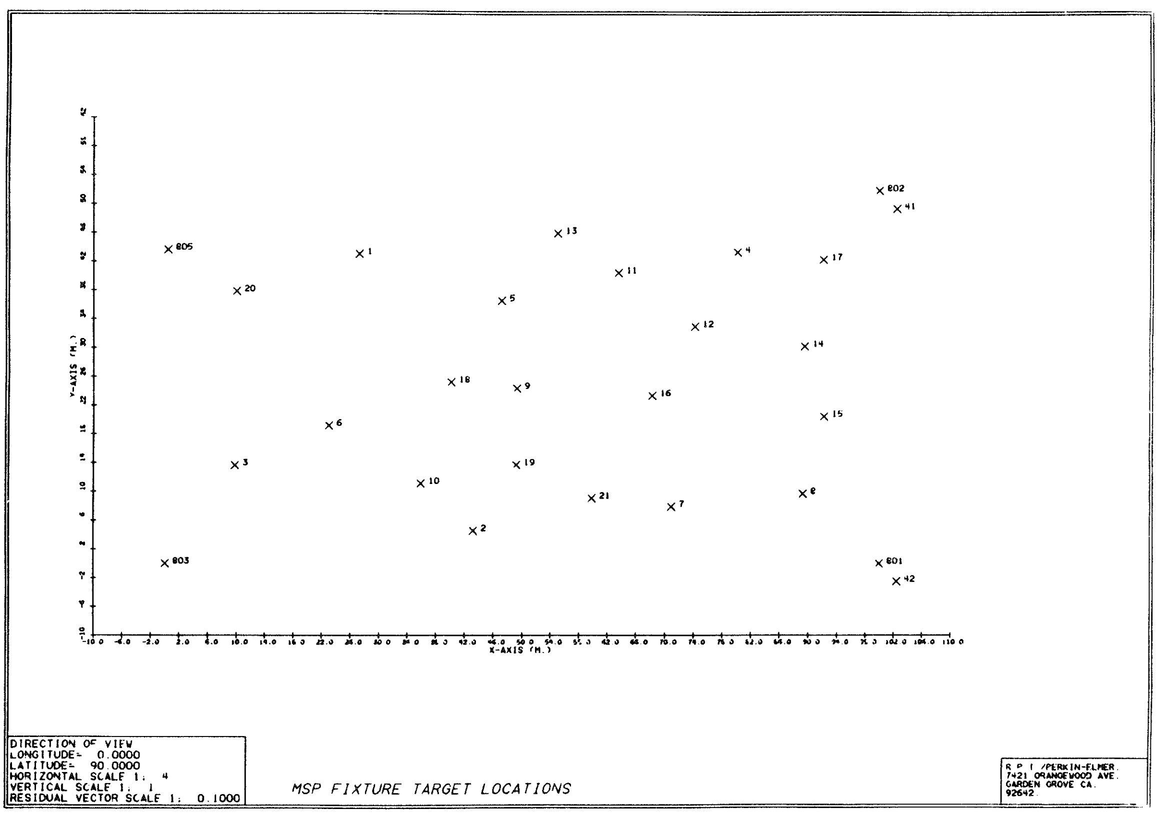

FIGURE 3

SUMMARY AND CONCLUSION

All cameras used in this test provided excellent results, although the U.M.K. camera provided the highest accuracy. Since only Select flat glass plates were used for this test it would be interesting to test the same camera using Ultra-flat glass plates. The accuracy obtained by the U.M.K. was better than what was simulated. One explanation for this accuracy could be the plate thickness and or the plate holders used by GDFW., also the platen on the Pass 2000 stage was within 1 micron in flatness.

This test including past and present project work proves that automatic target readings provided by a precision instrument provides accuracy in the realm of 100 percent over existing manual measurement systems. The accuracies obtained from the 35mm camera used in this test are comparable to some metric camera images measured on standard manual photogrammetric instruments. All image coordinates measured for this test were with the CCD detector only. Measurements using the PMT detector are normally 15 percent more accurate than the CCD.

For clients who do not need all the capabilities the Pass 2000 system offers, a new system with stage, computer and sensor could be made avaliable and still allow for expansion at a later date. This system is the MiniPASS.

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