A COMPARISON OF THE PERFORMANCE OF DIGITAL AND CONVENTIONAL NON-METRIC CAMERAS FOR ENGINEERING APPLICATIONS

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ABSTRACT:

This paper compares the performance of an off-the-self digital camera with that of a non-metric film based camera for structural deformation monitoring.
A Fujix DS-100 still digital camera and an Olympus OM 10 non-metric camera were utilized to determine the deformation of a structural model for a light weight roof when different loads were applied.
For this comparison, the same photogrammetric network design, control configuration and self calibrating bundle adjustment were used for data evaluation.
The results obtained illustrate the potential of digital cameras for such engineering applications.

KURZFASSUNG:

In diesem Artikel wird die Leistungsfähigkeit einer Digitalkamera für Deformationsmessungen mit der einer herkömmlichen Amateurkamera verglichen.
Die Digitalkamera FUJIX DS-100 und die Amateurkamera OLYMPUS OM 10 wurden zur Deformationsmessung eines Flächentragwerkmodells unter verschiedenen Belastungen eingesetzt.
Zu Vergleichszwecken wurde dieselbe Aufnahmeanordnung, Passpunktverteilung und Bündelausgleichung mit Selbstkalibrierung gewählt.

1. INTRODUCTION

Among all the present methods for deformation monitoring, close-range photogrammetry is well suited as a precise, non-contact, and rapid approach, especially for model studies. Basically, deformation monitoring constitutes a special application of point determination methods, using precise coordinate measurements of identical object points in two or more epochs (Ackermann, 1994).

Analytical close-range photogrammetry has reached a high level of accuracy which has made it feasible and practical for precision work. Digital close-range photogrammetry has become a recent competitor for most applications. Its main advantages are the ease and speed, as well as accurate and automated data acquisition and evaluation.

The development in digital photogrammetric techniques has reached a high degree of maturity such that it can be used in a variety of different applications (Grün, 1994). One of these applications is in structural deformation monitoring using a test model.

In this paper, the performance of a digital camera is compared to that of a non-metric film based camera for deformation monitoring. Model preparation, network design, data acquisition and evaluation are briefly discussed. Results and conclusions are presented.

2. MODEL PREPARATION

A structural model of a light weight roof was utilized to compare the performance of an off-the-self digital camera with that of a non-metric camera. This model consists of a wooden box, 94 cm long and 63 cm wide, the height along the longer walls was 15 cm, and 26 cm along the shorter ones.

A wire net of 11 x 17 wires was spanned from opposite walls, simulating hanging and standing cables. Adjacent wires were separated by 5 cm in both directions, forming 187 intersections which were used as deformation monitoring points for the roof surface.

In order to provide the best definition and identification of these points, both size and colour of the wires had to be optimized. Wires with diameter of 8.5 μm were most suitable for the selected photo scale ranging from about 1:90 to 1:300. The black colour for the wires provided the best contrast to the white background.

Fig.(1) illustrates the roof model and also shows the arrangement of the ground control points.

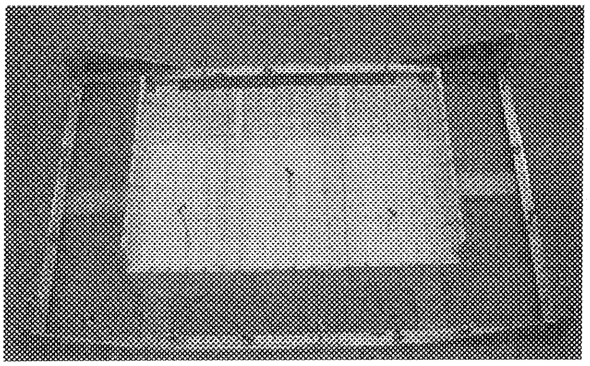

Fig.(1) The Structural Model with Control Points

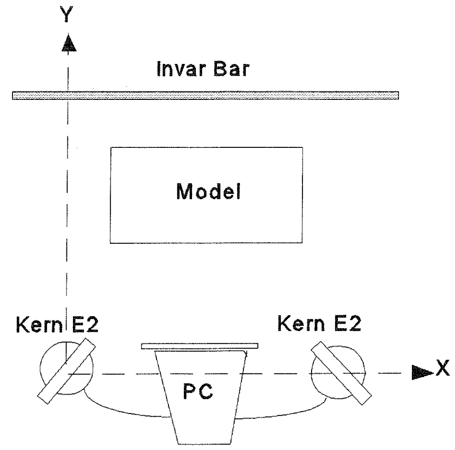

Fig.(2) Control Survey Configuration

3. COORDINATION OF OBJECT SPACE CONTROL

As shown in Fig.(1), 18 control points with different elevations were placed around the model with 3 more located inside the model to improve the geometry of the photogrammetric network.

Similar to the wires, the shape, size, and colour of the control targets were investigated. Either square or circular targets with a black and white combination for contrast were found to be the most suitable for all cases. Their size of 1 cm accommodates the range of photo scales used.

Since the accuracy of the control points directly influences the photogrammetric results, a control survey of high accuracy was carried out using an Electronic Coordinate Determination System. This near real-time 3D coordinate measuring system consists of two one-second electronic theodolites (Kern E2) interfaced with an IBM PC computer.

A 2 metre invar bar with a calibrated length of 2.10053 m was used to provide the scale of the system. As illustrated in Fig.(2), a near ideal configuration was selected for the control survey.

The observation procedure is similar to traditional intersection with horizontal directions and zenith distances observed for each point to be coordinated. The observed values are directly fed into the computer for further processing, therefore, no hand-booking is required. Immediately after each observation set, a bundle adjustment was carried out to acquire 3D coordinates for all the unknown points as well as pertinent accuracy information.

All horizontal directions and zenith distances were observed in two sets. The average standard deviation for the final coordinates of the control points were 0.03 mm, 0.025 mm, 0.02 mm in X, Y, and Z directions, respectively.

4.IMAGE CONFIGURATION

Generally speaking, deformation monitoring with photogrammetric techniques is based on taking some photographs before and after the deformation from appropriately located camera stations (Erlandson, 1975). After the data evaluation, two sets of 3D coordinates of the detail points (intersections in our case), which represent the roof surface, can be obtained for both epochs. The differences between the two sets of coordinates represent the deformation information.

Since geometric configuration is one of the main factors that influence the final accuracy, sophisticated methods have been designed especially for the purpose of network design (C.S.Fraser, 1984). In our case of study, a multi-station convergent photogrammetric network was established to monitor the deformation.

Taking into account the economical factor, as well as the uniform accuracy desired for the three directions X, Y, and Z, three camera stations were selected with 100% overlap for any pair of convergent photos. Fig.(3) illustrates the camera location lay out.

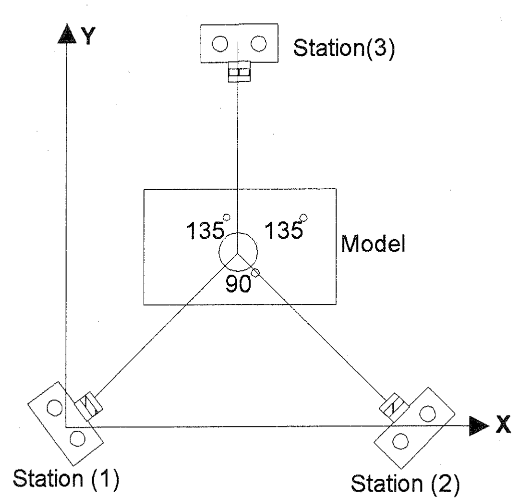

Fig.(3) Camera Locations Lay out

Photographs were taken at each station before and after deformation with both cameras from the same stations and with the same orientation. Due to the difference in the format of the imaging area for the two cameras (i.e. the area of the emulsion for the non-metric camera and the CCD frame in the digital camera), and the difference in the focal lengths, two options were available, namely to keep the camera-to-object distance unchanged and get a different photo scale for each camera, or else to keep the photo scale constant and change the camera-to-object distance.

From a practical point of view, the first option was chosen. The second option was difficult to achieve due to the expected short depth of field, which would prevent a clear and sharp image of the whole model. The camera-to-object distance was chosen to be 2.5 m which resulted in a photo scale of 1:90 for the non-metric camera, and 1:315 for the digital camera. The deformation was facilitated by changing the tension of the standing wires, which in turn affected the hanging wires as well.

5. INSTRUMENTATION

The non-metric camera used is an Olympus OM10 equipped with 28 mm nominal focal length, 36 mm x 24 mm image format, f-stop ranges from 2.8 to 22, an automatic exposure time adaptor and four artificial fiducial marks which had been placed in the photo plane for another project. The recording medium was a Kodak Elite 400 diapositive colour film.

While capturing the images, f/22 was selected as aperture, which represents the smallest diaphragm opening of ~1.3 mm, to maximize the depth of field. The regular illumination of the laboratory dictated an exposure time of 1 sec.

A Fujix DS-100 digital still memory card camera was also utilized. It is an off-the-self, low cost digital camera, not specifically designed for scientific or photogrammetric purposes. It can be considered as a non-metric digital camera because it has similar unstable geometric characteristics as conventional cameras, except for the recording medium.

Its focal length varies between 8 to 24 mm for the Fujinon 3X power zoom lens with f-stop ranges from 2 to 11 and exposure time settings of 1/4 to 1/750 sec. The picture element is a CCD (Charge-Coupled Devise) solid state image sensor. The camera has a frame of 720 x 488 pixels with a pixel size of 8.5 μm x 9.7 μm. The storing medium is a IM-85 Image Memory Card with 8 Mbyte capacity. The images stored in the card can be displayed and resampled on the computer using the DP-100 Memory Card Processor and SD-PC (Digital Still Camera System Image Handling) software. The resampled image has dimensions of 640 x 488 pixels with a square pixel size of 9.7 μm x 9.7 μm.

For image capturing, the minimum focal length 8 mm was chosen to obtain the maximum angular field of view. Again, the maximum f-stop=11 along with the maximum exposure time (t=1/4 sec) were chosen.

In addition to two sets of 6 images each (hard-copy film and digital), a third set was obtained by scanning (digitizing) the hard copy images. A Nikon scanner for slides was used for this task. The scanning resolution was 59 DPMM (dots per millimetre) and the final resolution for the output image was 101.7 P/mm (pixel per millimetre). This final resolution led to 9.8 μm x 9.8 μm pixel size.

The output image was chosen to have a format of 1.325 cm x 1.000 cm which produced a frame of 13475 x 10170 pixels. Due to the differences in image formats between the hard-copy and scanned images, the photo scale for the scanned images was calculated to be 1:157.5 with a hypothetical focal length of 16 mm.

6. PHOTO MEASUREMENTS

Photocoordinates are the fundamental input for the analytical photogrammetric adjustment. The accuracy of the final results is directly affected by the accuracy of the measurement of the photo coordinates. Due to the fact that we have two different types of information, analogue images and digital images, two different photocoordinate measuring instruments were needed.

For the hard-copy images, the analytical plotter Wild BC2 was used in monocomparator mode to measure the photo coordinates of the 6 photos. Each photo was observed three times. The average photo coordinates and their standard deviations were calculated. An average standard deviation for each photo was also calculated to provide an indicator of the observation precision. Table(1) illustrates the precision of the observations for both epochs.

Station	Before Deformation		After Deformation	
	X (μm)	Y (μm)	X (μm)	Y (μm)
(1)	3.89	4.29	3.03	3.1
(2)	5.56	6.13	4.28	4.69
(3)	4.25	5.08	3.13	3.98

Table(1) The precision of the observations for hard copy images (in μm at photo scale)

The photo coordinates of the digital images were measured with the Leica DVP (Digital Video Plotter) system. Some the advantages of DVP are its a very powerful photogrammetric software, its low cost compared to any other digital photogrammetric workstation, its suitability to be installed in any ordinary PC with no need for a high capacity hard drive, and its subpixel accuracy in measuring the photo coordinates, which compares well with the accuracy of any analytical plotter.

Again, each image, either digitally collected or scanned, was measured three times and the average values and standard deviations for all photo coordinates were calculated. Tables(2) and (3) illustrate the precision obtained in measuring the photo coordinates of the digital images in both pixels and μm.

Station	Before Deformation				After Deformation			
	X		Y		X		Y	
	pixel	μm	pixel	μm	pixel	μm	pixel	μm
(1)	0.08	0.78	0.11	1.03	0.05	0.50	0.06	0.57
(2)	0.07	0.65	0.08	0.82	0.05	0.51	0.07	0.64
(3)	0.06	0.62	0.07	0.71	0.04	0.43	0.06	0.55

Table(2) The precision of the observations for the digital photos

Station	Before Deformation				After Deformation			
	X		Y		X		Y	
	pixel	μm	pixel	μm	pixel	μm	pixel	μm
(1)	0.10	1.00	0.14	1.33	0.13	1.23	0.10	1.00
(2)	0.13	1.25	0.13	1.30	0.11	0.96	0.09	0.92
(3)	0.09	0.93	0.08	0.83	0.07	0.66	0.08	0.74

Table(3) The precision of the observations for the scanned photos

7. DATA EVALUATION

After determination of the photo coordinates of the intersections and control points for all images, all three data sets, namely hard-copy, digital, and scanned, were evaluated. Each project requires two sets of photo coordinates to be processed, for three images before and after deformation.

Due to the unknown systematic errors of both the digital and non-metric cameras, a self calibrating bundle adjustment was selected for the evaluation (El-Habrouk et al.,1996). The program UNBASC2 (UNB Analytical Self Calibration) (Moniwa, 1977) has several advantage namely: no additional control information is needed for the calibration, no approximate values for the unknown parameters are required except for the principal distance, the calibration is photo-variant, and does not require fiducial marks as was the case for the digital camera.

The input data includes photo coordinates, control information, and the iteration sequence to solve sequentially for the unknown parameters. The output are the 3D coordinates for the unknown points in object space, camera calibration parameters as well as accuracy related information.

8. RESULTS

Fig.(4) illustrates the deformation behaviour of the roof model, as determined by photogrammetry.

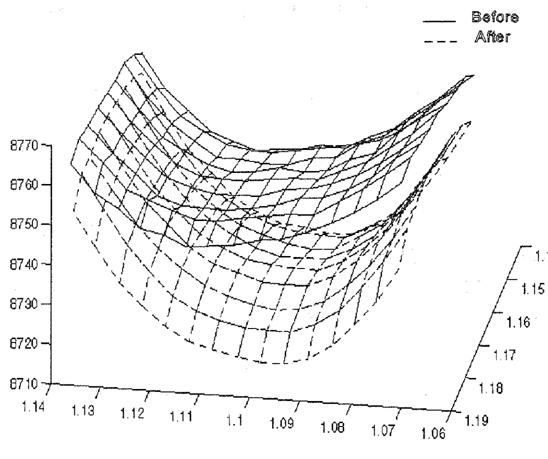

Fig.(4) The Deformation of the Roof Model

For the comparison of the different camera types, the pertinent accuracy information from the UNBASC2 output is summarized in tables (4) and (5).

Project	Before Deformation (μm)		After Deformation (μm)	
	RMS X	RMS Y	RMS X	RMS Y
Hard-copy	5.04	5.42	3.76	3.52
Digital	3.26	3.45	2.87	1.89
Scanned	5.21	3.25	3.56	2.09

Table (4) RMS values for the photo coordinates (In μm photo scale)

Project	Before Deformation (mm)			After Deformation (mm)		
	X	Y	Z	X	Y	Z
Hard-copy	0.38	0.18	0.29	0.07	0.21	0.62
Digital	0.16	0.06	0.20	0.28	0.42	0.48
Scanned	0.53	0.31	0.54	0.49	0.75	0.31

Table (5) RMS values for check points (in mm object scale)

Table (4) provides the RMS values for the photo coordinates for both epochs, while table (5) lists the RMS values for the check points coordinates in object scale. It is obvious from these results that submillimetre accuracies were achieved with both cameras. The digital camera clearly matches the non-metric one in accuracy.

9.CONCLUDING REMARKS

This comparative study of the performance of digital and film based non-metric cameras has shown that digital off the self cameras provide photogrammetric accuracies that are equivalent to the ones obtained with film based cameras. In fact the test results show a slightly higher accuracy for the digital camera, which is remarkable, especially for the check point results because of the smaller photo scale.

As long as the restrictions due to the smaller format can be tolerated, the use of a digital camera provide operational advantages without sacrificing accuracy. Furthermore, the slight reduction of accuracy for the evaluation of the scanned data at the check points is well within the requirements for the project. Therefore, digital evaluation of non-metric photography is most suitable for such projects.

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