Non-metric Photogrammetry and Surveyors

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Abstract

The costs and benefits of using terrestrial photogrammetry to gather field information is examined. A study of the results obtained with different types of cameras on a survey for dam deformation measurements is presented so that the range of accuracies that may be expected in practice can be compared. The paper explains in simple terms the differences between "metric" and "non-metric" cameras and various photogrammetric adjustment techniques. It discusses the main problem areas to be overcome including the high cost of analytical stereo-plotters or precise image co-ordinate measuring machines which are essential if the full potential of analytical photogrammetry is to be realised.

Introduction

The last decade has seen a number of changes, both technological and social, which can be construed as an indication that surveyors will be making greater use of terrestrial, and to some extent aerial, photogrammetry in the future. These changes include:

- higher labour costs associated with field work;
- a greater awareness of safety regulations and the hazardous nature of the surveys required for volume determinations of stock piles and storage bins;
- ready access to mini- or micro-computers and photogrammetric software packages;
- research experiences in analytical photogrammetry at several Australian universities and surveying teaching institutions;
- improvements in the quality of lenses and films for small format cameras;
- revival of the "age-old" claim that photogrammetry offers a cheaper solution.

Photogrammetry may provide the means for surveyors to move into measurement areas which have not yet been commercially explored. Professor E. H. Thompson (1962) acknowledged that there were difficulties associated with the photogrammetric method but stated that "photogrammetric methods of measurement are useful in the following conditions:

(i) when the object to be measured is inaccessible or difficult to access;

(ii) when the object is not rigid and its instantaneous dimensions are required;

(iii) when it is not certain that the measurements will be required at all;

(iv) when it is not certain, at the time of measurement, what measurements are required;

(v) when contours of the surface are required;

(vi) when the object is very small, especially if it is microscopically small."

The following sections present to the practising surveyor an explanation of some of the jargon of non-topographic photogrammetry and provide a study of the accuracies obtained on a recent project where a range of cameras, films and

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calculation methods were used. It is acknowledged that some of the finer details of the photogrammetric techniques have been omitted from the following discussions, for the sake of brevity.

Metric and Non-metric Cameras

Traditional photogrammetry has been based on the use of very specialised cameras known as metric cameras.

Metric cameras (after Fraser, 1982) usually have:

- been specifically designed for photogrammetric purposes and take large format photographic images on stable-base film or glass plates;
- a stable interior orientation, that is the lens cone is rigid and the focusing distance pre-set at the factory. The optical axis is defined by fiducial marks fixed to the camera which are reproduced on each exposure as reference points;
- a low distortion lens whose characteristics (focal length, radial lens distortions) are known from a manufacturer's calibration test;
- an image surface which is flat within a fine tolerance and which incorporates a film flattening device such as a pressure plate or vacuum system.

Non-metric cameras, in general, do not possess any of the desired features listed above for metric cameras. However, they do have several relative advantages.

They are:

- readily available — they may be bought over the counter at any camera store for prices from $200 to $2,000 compared with $7,000 to $35,000 for metric cameras;
- light in weight and can be hand-held;
- capable of interchanging lenses and focusing for any camera-object distance;
- often motor-driven, allowing for a rapid succession of photographs;
- able to accept roll film that can be purchased in small quantities and can be commercially processed.

Some of the disadvantages of non-metric cameras need to be recognised to present a balanced view. These include:

- an unstable interior orientation, that is, the effective focal length may change for each exposure and the direction of the optical axis may alter with focusing movements;
- a lack of fiducial marks;
- irregular lens distortions. As well as radial lens distortions, relatively large tangential distortions may be present in the lenses of older amateur cameras. These are more difficult to compensate during subsequent calculations of object positions;
- an unsophisticated film flattening device. The film may be buckled at the time of exposure, but will be held flat whilst image co-ordinates are read from it. The buckling may vary from frame to frame and consequently is very difficult to correct during calculations for object co-ordinates;
- roll film which is not on a stable base and may become distorted during commercial processing. Note that Kodak did introduce a stable base black and white 35 mm film in 1983. Known as Kodak Technical Pan 2415, this film has a very fine grain and is suitable for examination under high magnification;

- small image format. The accuracy of determining the position of an object by photogrammetry is claimed to be directly related to the area of the photographed image (Brown, 1982). For example, if two photographs are taken of an object with a camera that has a 100 mm by 100 mm format area then approximately 20 photographs must be taken with a 35 mm camera (format size, 24 mm by 36 mm) to obtain comparable accuracy. This argument is only valid if the lenses of each camera are assumed equal in quality.

  The modern lenses available for small format non-metric cameras often have a better pictorial quality than the low distortion and lower resolution lenses in metric cameras. There is a "trade-off" between lens distortions and resolving power, so whilst the small format images have larger lens distortions, they are capable of examination and measurement under higher magnification. With computer processing counteracting the lens distortions and the resolving power of the small format camera lenses continually improving, the claim that accuracy is directly related to format area may need to be revised.

Computation Methods

The traditional approach to terrestrial photogrammetry has been to simply rotate aerial photogrammetry through 90°, that is, to use cameras that were similar to aerial survey cameras and take exposures with parallel camera axes perpendicular to the plane of the object. For example, a building photographed from across the street could then be observed in most of the conventional analogue stereoplotters. Until mini-computers with suitable software became commonplace from the mid-1970s or analytical stereoplotters began to make in-roads into mapping agencies in the 1980s, terrestrial photogrammetry was constrained to follow rigid procedures.

Most, if not all, of the errors caused by the limitations of non-metric cameras can be compensated for with computer-based methods of photogrammetry. If three or more control points can be seen in each image, then the focal length, which may vary from photograph to photograph, and the exact location and orientation of the camera can be determined during computer processing. This "self-calibration" may also involve assessment of eccentricity of the optical axis and the amount of film distortion.

To summarise the modern approach to terrestrial photogrammetry, it is possible and practical to use a non-metric camera to photograph an object from several directions, not constrained by parallelism of camera axes. Processing the resulting images may broadly be thought of as taking one of two forms:

(i) If the camera axes do not differ in direction by more than about 35°, then stereoscopic vision is possible and co-ordinate information may be extracted from an analytical stereoplotter. This technique would be chosen when a large amount of co-ordinate data is to be gathered, e.g., contouring or taking profiles across stockpiles, or detailed plotting of building facades.

(ii) If multiple photographs have been taken from widely varying directions (up to 180° different in bearing), and/or the co-ordinate information required involves distinct points or targets, then the technique most usefully employed may be to obtain (x, y) co-ordinates for each point on each photograph from either a mono- or a stereo-comparator. Computer software is available which firstly computes resections to determine locations of camera stations and then uses these results to determine the target co-ordinates on the object by a least squares solution of all the intersecting rays from the camera stations. Surveyors should not find difficulty with this technique; it is directly analogous to using theodolites to observe directions to a series of known and unknown targets, calculating resections to determine the co-ordinates of the theodolite stations and then calculating intersections for the unknown target co-ordinates.

For objects that can be stereoscopically covered by a single pair of photographs, the above techniques may suffice. If the size or shape of the object is such that it cannot be conveniently photographed in this manner then further computer processing using the techniques known as independent model adjustment or bundle adjustment may be necessary.

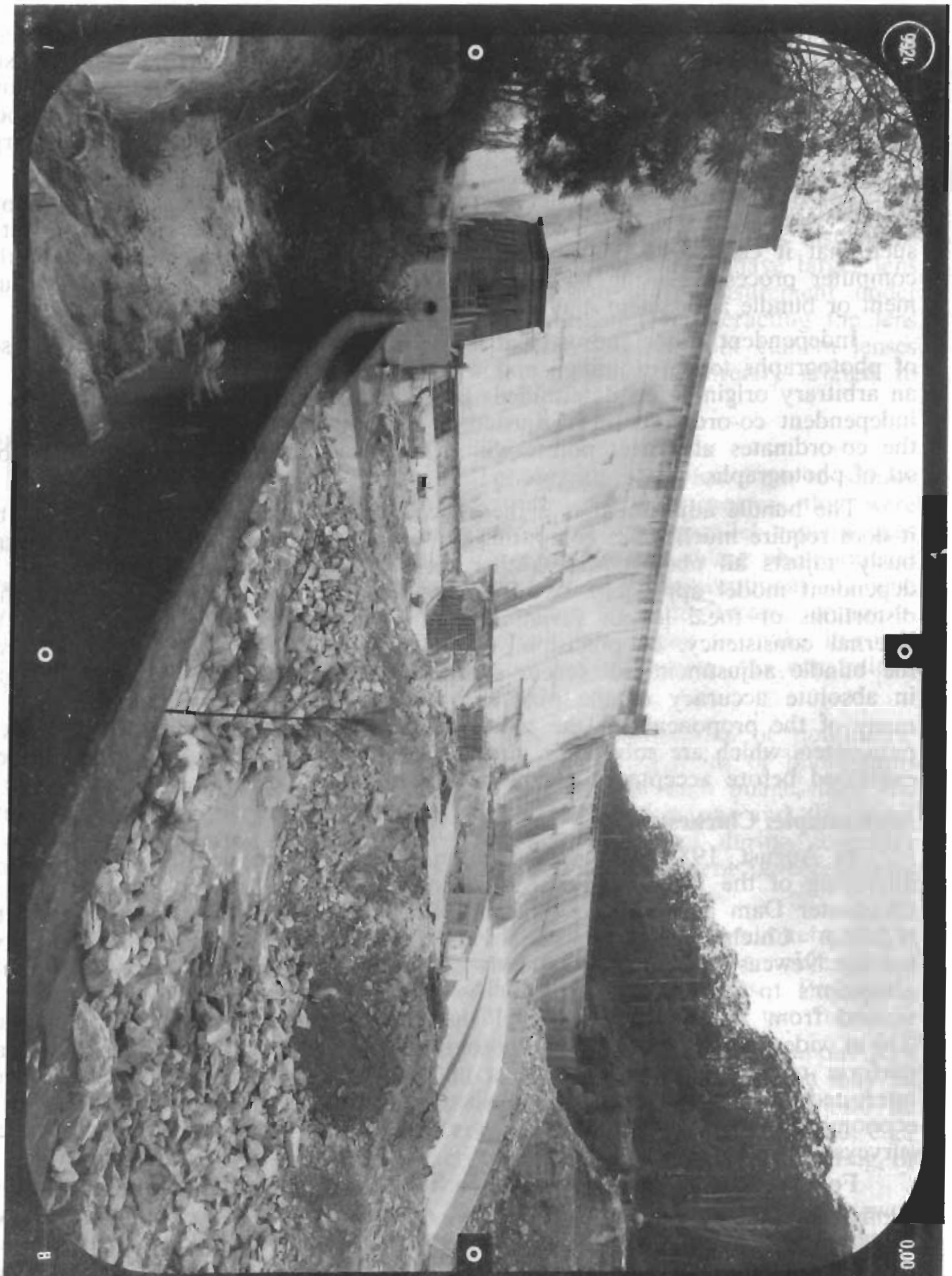
Independent model adjustment is a technique which allows pairs or sets of photographs to be examined and a set of object point co-ordinates based on an arbitrary origin to be determined. From each set of photographs, the sets of independent co-ordinates are adjusted to a common datum by comparisons of the co-ordinates at object points which have been observed in more than one set of photographs.

The bundle adjustment is a theoretically stronger method of adjustment but it does require much more computing power. In this technique which simultaneously adjusts all observations (rather than in two or more stages like the independent model approach), extra unknown parameters such as non-linear film distortions or focal length variations can be determined. An increase in the internal consistency, or precision, of the adjusted quantities is obtained from the bundle adjustment but recent studies (Fraser, 1982) indicate that the gain in absolute accuracy of the object co-ordinates may not be as significant as many of the proponents of the bundle approach originally believed. The extra parameters which are solved for must be carefully considered and their solutions evaluated before acceptance of the results of any adjustment.

An Example: Chichester Dam

In August, 1983, Dr M. Shortis and Mr C. Ogleby of the Department of Surveying of the University of Melbourne and the author took photographs of Chichester Dam at the request of the Hunter District Water Board (Newcastle, N.S.W.). Chichester Dam is one of the main catchment and storage reservoirs for the Newcastle region. It is nearly 60 years old and is undergoing structural alterations to increase its capacity by raising the height of its spillway. As viewed from the downstream side, the dam is approximately 35 m high and 230 m wide across the crest (see Photograph 1). Surveyors from the Water Board perform regular monitoring surveys of the structure and surrounds and were interested in a pilot study to see whether terrestrial photogrammetry could be economically used to supplement, or even replace, their conventional geodetic surveys.

For the purpose of this study, a total of 17 targets was placed in two rows near the top and base of the dam wall (Figure 1). A Zeiss (Jena) UMK camera which accepts glass plates was borrowed from the University of Wollongong for the survey. It was expected that the accuracy of the co-ordinates derived by photogrammetry would be of the order of ±2 to ±3 mm, that is, comparable with existing survey methods.



Photograph 1: Chichester Dam from Camera Station 1

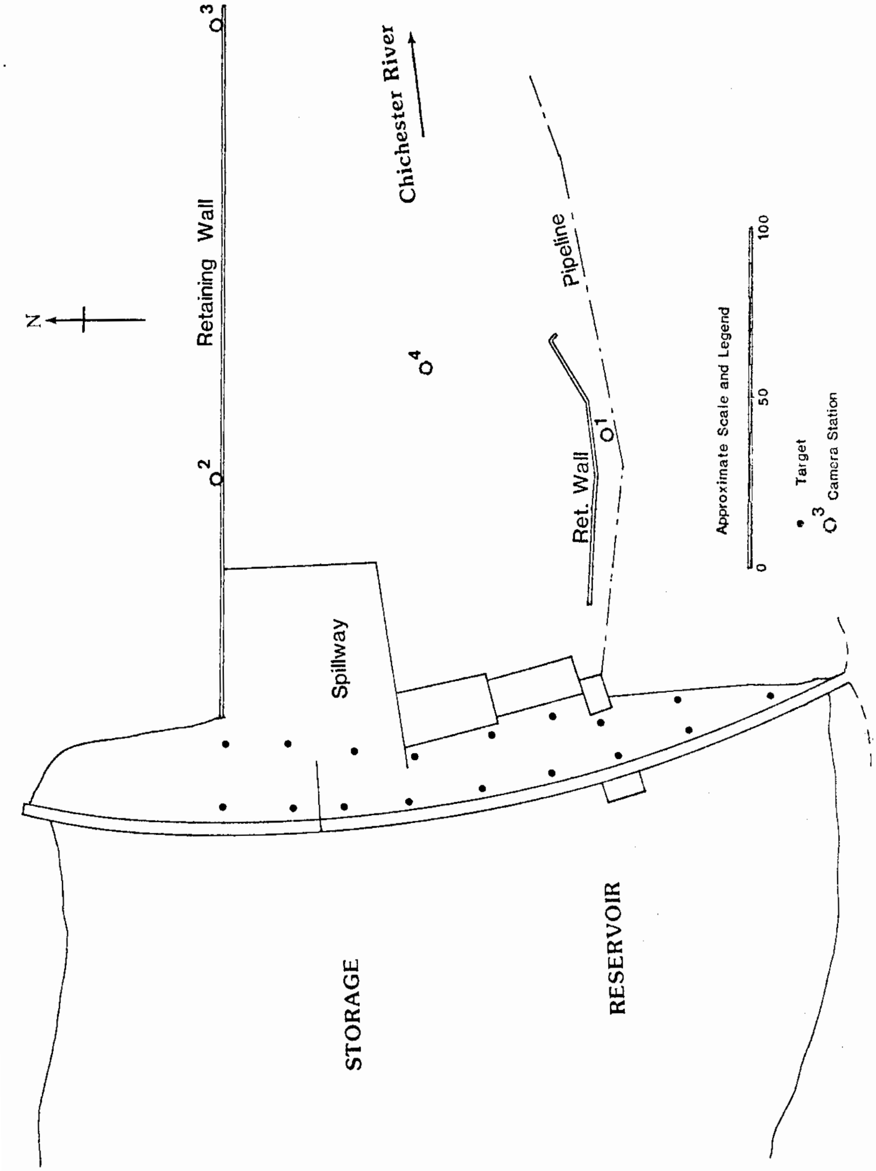


Figure 1: Camera Stations and Target Locations for Chichester Dam Study

Four camera stations were selected, ranging in distance from 120 m to 240 m from the dam wall. The camera stations were not in the optimum locations for a precise result due to the difficulties of a construction site, but were the easiest to occupy in the limited time available. In a three hour period, two to four photographs were obtained from each station with the Zeiss UMK. To provide comparisons on the precisions attainable by other types of cameras, both metric and non-metric, other sets of photographs of the targets were taken with a Wild P-32, a Hasselblad 500 ELM and a Canon AF35M camera using both black and white and colour slide transparency films. Table 1 gives a brief comparison of the costs, format size and focal lengths of the cameras used. The three hour period to perform all this field work should be compared with the four nights of observations usually involved with deflection surveys at Chichester Dam (plus overtime, living away from home allowances, etc.).

Table 1: Cameras used in Chichester Dam Study

Camera (Type)	Focal Length mm	Image Size mm x mm	Approx. Cost $
Zeiss Jena UMK (metric)	100	180 x 130	35,000
Wild P-32 (metric)	64	90 x 65	7,000
Hasselblad 500 ELM (non-metric)	51	60 x 60	5,000
Canon AF35M	38	36 x 24	200

The method of reduction was to observe plate co-ordinates on each photograph on a comparator-type device. The most precise (±0.002 mm) of these comparators was the Zeiss (Jena) Stecometer Stereocomparator at the University of Melbourne. The UMK glass plates and the Hasselblad photographs were measured on this device. The P-32 and Canon camera photographs were initially measured at the University of Newcastle on a Kern PG-2 stereoplotter which had been fitted with a tri-axis locator and digital read-out system to a precision of ±0.01 mm. Comparisons of repeated measurements indicated that the mean of two or three sets of readings had a precision of ±0.007 mm. It was later believed that a more accurate result could be obtained for the object targets from more precise plate co-ordinate readings, so these photographs were fully re-observed on a Wild A8 with digital encoders at the University of New South Wales to a precision of ±0.004 mm.

The computer processing was done by two methods: the relatively simple resection/intersection technique and the more time-consuming bundle method approach. Table 2 provides full details of the precisions obtained.

The overall precision of a photogrammetric survey is often quoted as the ratio of the vector of positional error and the maximum dimension of the objects surveyed (Brown, 1982). Other researchers refer to the ratio of the positional error and the camera to object distance (Karara, 1979, p. 95). In this case there was not much difference, with the distance between extreme targets being 175 metres and the average camera to object distance 160 m. Accuracies of up to 1 : 250,000 have been obtained in some overseas studies (Brown, 1982) where plate co-ordinates have been observed on comparators which measure to a precision of ±0.001 mm and the cameras and glass plates have been specially calibrated. Non-metric camera results to an accuracy of 1 : 10,000 have also been reported (Fraser, 1982).

Table 2: Comparison of Results for Chichester Dam Study

Camera	Precision of Comparator Measurements	Standard Errors of Co-ordinates In Plane of Dam Wall North	Standard Errors of Co-ordinates In Plane of Dam Wall Height	Towards Camera East	Vector (mm)	Accuracy	Adjustment Procedure
Zeiss Jena UMK	0.003	1.9	1.9	4.1	4.9	1 : 35,700	Bundle
Wild P32	0.007	17.7	8.7	22.1	29.6	1 : 5,900	Resect/Intersection
	0.007	11.2	9.0	22.1	26.3	1 : 6,600	Bundle
	0.004	10.3	7.4	22.4	25.7	1 : 6,800	Resect/Intersection
	0.004	9.8	7.9	20.8	24.3	1 : 7,200	Bundle
Hasselblad 500 ELM	0.003	12.4	7.5	24.4	28.3	1 : 6,100	Bundle
Canon AF35M	0.007	50.6	40.1	81.6	104.0	1 : 1,700	Resect/Intersection
	0.007	45.4	33.9	46.1	73.0	1 : 2,400	Bundle
	0.004	37.8	23.4	56.9	72.2	1 : 2,400	Resect/Intersection
	0.004	26.7	22.9	45.3	57.3	1 : 3,000	Bundle

The results obtained at Chichester Dam were slightly disappointing, being approximately a factor of two worse than expected. A closer examination of the Chichester Dam photogrammetric survey indicated that the camera locations were not selected in locations suited to optimum accuracy and the UMK camera was in need of calibration (Shortis, 1983). These shortcomings aside, the results shown in Table 2 can be summarised with a few remarks which, upon reflection, are largely self-evident but still worthy of mention.

(a) The most expensive equipment using glass plates rather than roll film provided the most precise results.

(b) The larger the film format, the more precisely the target co-ordinates were determined (see comparisons in Table 3). The results for the small format Canon camera were better than one would have expected on the criterion of accuracy related to image format area.

(c) The more precisely the plate co-ordinates were measured, the more precise the final result for object co-ordinates. It had been anticipated with the non-metric Canon camera that uncertainties in the focal length and optical axis definition, film deformation and lack of fiducial marks would mask any possible improvement in accuracy that should be gained from more precise measurement of the image co-ordinates (±0.004 at the University of New South Wales, compared to ±0.007 at the University of Newcastle). This was not the case as can be seen from Table 2.

(d) The accuracy of determining the target co-ordinate in the direction from the camera to the dam wall was always worse, by a factor of two on average, than the other two co-ordinates which lie in the plane of the dam wall. This situation is directly analogous to aerial photogrammetry where the height value is always less accurate than co-ordinates for planimetric position. This problem is directly related to the geometry of the intersecting rays, and can be alleviated to some extent in terrestrial photogrammetric networks by wise selection of camera stations and camera axis orientation.

Table 3: Comparison of Image Areas and Results

Camera (glass/film)	Image Area mm^2	Accuracy of Results
Zeiss Jena UMK (glass plates)	23,400	1 : 35,700
Wild P-32 (roll film)	5,850	1 : 7,200
Hasselblad 500 ELM (roll film)	3,600	1 : 6,100
Canon AF35M (roll film)	864	1 : 3,000

Non-metric Cameras and Surveying Practice

The results of the Chichester Dam study which are of most interest to practising surveyors concern those of the non-metric $200 Canon camera which used Kodak ASA 64 colour slide transparency film. This is the style of camera which most people own for private snap-shots. In fact, most surveyors would probably have access to a slightly more expensive single-lens-reflex (SLR) camera which could be expected to provide improved results as most SLR cameras are more solidly constructed than the camera used in this test. A range of accuracies from 1 : 1,500 to 1 : 3,000 was obtained with the Canon AF35M camera, so an average figure of 1 : 2,000 could be expected under most circumstances with a little care.

Translated into basic surveying terms, 1:2,000 means that if an object such as a stockpile 50 m long by 10 m wide by 10 m high were photographed, then the standard error in position of any point determined photographically would be approximately ± 25 mm. This figure is probably unrealistically precise for the case of a stockpile where each point will not be targeted nor imaged on several photographs (as was the case at Chichester Dam) and where the nature of site will restrict camera locations which could provide "ideal" intersections of imaging rays. A figure of ± 75 mm may be more likely on a difficult site. If regular monitoring is required, as is usual with stockpiles, the initial establishment of a control traverse with precisely surveyed camera station locations would strengthen the computational procedure as the camera stations would not enter the solution as unknowns.

Another surveying task that is occasionally encountered is the detailed measurement of a building facade prior to re-development in city areas. This task is well suited to photogrammetry as there is usually little relief in the facade so that errors in the direction from camera to object are not critical. Assuming photogrammetric accuracy of 1:2 000 and a building 25 m wide, then the likely vector of positioning error is ± 12 mm. This vector would probably be composed of errors in the plane of the building facade of ± 5 mm and ± 10 mm in facade depth.

The Difficulty

If so much field time can be saved by simply taking photographs, why aren't surveyors out with their cameras as a regular occurrence? There are only four basic steps in performing a photogrammetric survey. They are:

(a) taking the photographs and obtaining a few field control measurements;

(b) measuring the image co-ordinates on either a comparator or a stereo-plotters;

(c) running the computer programs to convert image co-ordinates to object co-ordinates;

(d) plotting or computing the final result, for example, a volume.

Steps (a) and (b) are straightforward and step (c) has become possible in the last four years as most surveyors have access to powerful mini-/micro-computers and software for analytical photogrammetry has been published (e.g., Marzan and Karara, 1975, Argyris *et al,* 1972, Wolf, 1975) although most of these references do not have a wide circulation. The real problem for the "average" surveyor will be step (b) — measuring the image co-ordinates. It has been shown in Table 2 that the more precisely image co-ordinates are measured, the greater is the precision of the resulting object co-ordinates. Survey offices do not usually have a measuring device more precise than an eye gauge which can only measure from ± 0.05 to ± 0.1 mm over a limited area (e.g., a circle of diameter 20 mm).

In the earlier section on computation methods, reference was made to the two basically different approaches which are taken to solve analytical photogrammetric problems:

(i) image co-ordinates are measured separately off each photograph if only relatively few distinct or targeted points are required (e.g., Chichester Dam study), and

(ii) analytical stereoplotters are used to extract strings of co-ordinates from overlapping stereopairs if many points are required for dense detail surveys or contour information.

The targeted points in the Chichester Dam study were measured on equipment at the Universities of Melbourne, New South Wales and Newcastle. The private practising surveyor does not have the same ready access to use this specialised equipment because, although it may be true that it lies idle for part of the year, there are periods of time when it is extensively used by staff and students in the course of their studies.

Supposing that a private survey practice wishes to commence terrestrial photogrammetry and does not want to rely on the availability of outside measuring equipment, how much will it cost? The 1984 cost of a monocomparator is approximately from \$20,000 upwards, with stereocomparators approximately \$10,000 extra. The only cheaper device which can provide image co-ordinates to the order of ± 0.002 mm is a microscope fitted with a special measuring stage. These will usually only cover the area of small format films but still cost around \$12,000 with a digital display. Such a microscope and stage is an instrument not capable of expansion if the surveyor decides to try the larger film formats which can provide a more accurate result.

The only real alternative to the comparator-type devices is the analytical stereoplotter that can handle non-metric terrestrial photogrammetry. The cost of these range from \$40,000 to \$300,000 with the Australian designed and developed QASCO SD-4 at the bottom end of the price range (Elfick and Fletcher, 1982). An analytical stereoplotter can be used as a monocomparator to obtain single plate co-ordinates if a situation should arise where stereoscopic vision is not possible, but its main advantage lies in its ability to rapidly provide co-ordinates for strings of contour lines or profiles. The \$40,000 price tag for an analytical stereoplotter seems to be incompatible with the cheapness of the other components in non-metric terrestrial photogrammetry. A single survey firm could find it difficult to justify such an expense although other items of equipment such as total station instruments and computers and plotters approach this figure. A consortium approach to the purchase of such a device may be a possibility for several firms working in close proximity. Hiring an analytical plotter for a week or two may be an economic proposition if a sufficient volume of work can be accumulated.

The use of consultant photogrammetric firms to undertake the plotting at contract rates would seem a reasonable alternative to the prospect of purchasing an expensive item of equipment. In this way surveyors would merely have to provide the photographs and some survey control information for the photogrammetrist. Such a liaison between practising surveyors and photogrammetric companies should have dual benefits: a saving in overall job costs to the surveyor and another avenue of employment for a photogrammetric industry which has had financial difficulties with a recession in the last five years.

Conclusions

Improvements in low cost small format cameras and ready access to analytical photogrammetric computer programs indicate that non-metric terrestrial photogrammetry may prove to be the most efficient solution to a number of surveying tasks where the work environment is hazardous (for example, storage bins) or the object to measure is in an awkward position (building facades). The greatest problem confronting the survey practice which wishes to perform the entire task itself is the cost involved in obtaining an instrument which can precisely measure the images on the photographs. Comparator-type devices are limited to situations where only comparatively few well-defined points need to be measured and analytical stereoplotters cost from $40,000 upwards. The shared use or hiring of an analytical stereoplotter may be a short-term solution although it is anticipated that as the cost of electronic devices continues to fall a cheaper second- or third-order analytical stereoplotter will come onto the market. The use of a specialist photogrammetric company is recommended for those surveyors who are willing to sub-contract the image-measuring process.

Postscript

It would seem appropriate to conclude with a statement made by Edouard Deville, Surveyor General of Dominion Lands, Canada, in 1895, after he had had eight years experience of photogrammetric surveying. "There is such a fascinating simplicity about the method, that it is at first difficult to understand the reasons which prevent its adoption. I soon discovered that the apparent simplicity is a delusion . . . the topographer requires not only experience but a combination of the facilities that make an accomplished photographer." (Thompson, 1966).

General Reading on Non-topographic Photogrammetry

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