

THE ARCHIVAL PHOTOGRAMMETRIC TECHNIQUE: FURTHER APPLICATION AND DEVELOPMENT

By J. H. CHANDLER and J. S. CLARK
City University, London

Abstract

The basis of the archival photogrammetric technique is reviewed briefly. Applications of the method in both research and commercial contracts are described and have resulted in further development of the method.

INTRODUCTION

THE ARCHIVAL PHOTOGRAMMETRIC TECHNIQUE is an analytical photogrammetric method which allows spatial data, of known quality, to be derived from archival or historical photographs. The technique was developed at City University between 1986 and 1989 to solve a particular geomorphological problem (Chandler, 1989). The technique is universally applicable to almost any type of imagery and since its original development the archival photogrammetric technique has been applied on several commercial contracts. Some of these applications have necessitated software enhancements and additional development of the overall method. The aim of this paper is to outline briefly the technique, indicate some of the more unusual commercial applications and describe associated software development.

THE ARCHIVAL PHOTOGRAMMETRIC TECHNIQUE

The technique and its original application have been reported previously (Chandler and Cooper, 1988 and 1989), so only brief details of the method are required here.

Problems with Archival Photographs

The main photogrammetric problem presented by using archival photographs for measurement is the likely lack of any calibration data associated with the original camera. This critical problem is resolved by making use of a self calibrating bundle adjustment in which both the interior orientation parameters are derived in one simultaneous least squares estimation. Other software modules provide starting values for the co-ordinates of all pass points and both co-ordinates and rotations of each photographic frame. These values are of sufficient quality to ensure rapid convergence of the final estimation and solve an important practical problem associated with the use of bundle estimating procedures.

The Method

The archival photogrammetric technique can be simplified into several distinct sections, which are carried out sequentially.

Photo acquisition. Suitable sequential contact diapositives must be acquired from one of the archive sources. Some of these sources are making use of computerised registers, so searches are becoming quicker. Although strictly only two photographs are required to derive three dimensional data, three or more

frames are preferred. Redundancy is particularly important for the reliable estimation of inner orientation parameters.

Identification and derivation of control. Co-ordinated points will often be unavailable, but control can be scaled from a local large scale plan. Additional control can be provided by measurements between points. These can include "natural" measurements, for example zero height differences between points defining the boundary of a lake. The stochastic properties of all co-ordinates and measurements should be judged, because the measurements are weighted in the final adjustment.

Image measurement. The image positions of control and pass points are measured using a stereocomparator or analytical plotter. Reference points such as corners or sides of the format can be used if suitable fiducials are not present.

Photogrammetric processing. Photogrammetric processing consists of a suite of four programs. The self calibrating bundle adjustment is the last and is used to estimate the exterior orientation parameters. Elements of inner orientation, which model the internal geometry of the camera, are also estimated. Two groups of these elements can be identified:

- (i) the primary inner orientation parameters, which model the displacement of the principal point relative to the reference marks and a correction to an approximate camera focal length; and
- (ii) lens distortion parameters (one or three parameters of an even powered polynomial used to model radial lens distortion and, optionally, two parameters used to model tangential lens distortion).

No explicit modelling for film deformation is included, because it is improbable that calibrated fiducial data are available.

The internal parameters can be included in various combinations, so that inestimable parameters can be dropped in an over-parameterised solution. Other important aspects of the program are the ability to include measurements between points which enables unconventional control to be included. Also, because the stochastic nature of co-ordinates and measurements is taken into account, data of various degrees of precision can be used. The self calibrating bundle adjustment overcomes rigorously many of the problems associated with historical photography.

Data extraction. When a satisfactory solution has been obtained, it is possible, using the estimated exterior and interior parameters, to extract the co-ordinates of new points anywhere on the site. This procedure is most effective if an analytical plotter is used. The Intergraph InterMap Analytic (IMA) analytical plotter at City University allows two forms of data extraction:

- (i) feature coding (delineation of boundaries, with lines of varying colours, linetypes and thicknesses);
- (ii) DTM collection (extraction of a grid DTM of any size and density).

Both of these programs enable high rates of data extraction, approaching 5000 points per day.

Original Application

The site that was used to both test, develop and demonstrate the archival photogrammetric technique was the Black Ven landslide complex near Lyme Regis, Dorset. A sequence of photographs was acquired, with photographic epochs spaced approximately every decade since 1946. The photographs included a variety of vertical and oblique aerial images acquired using an assortment of reconnaissance and survey type cameras. The sequence was completed in 1988 when a series of oblique small format photographs was acquired from a window of a light aircraft, using a hand held Rolleimetric 6006 camera. Measured data from all five epochs

were restituted successfully and a variety of spatial data was derived. These data were used to quantify the substantial changes that have occurred at this site since 1946 (Brunsden and Goudie, 1981; Chandler and Cooper, 1988).

FURTHER APPLICATION AND DEVELOPMENT

The ability to derive accurate three dimensional data from archival photographs has far wider application than simply geomorphology. Any science concerned with visible change in the environment can benefit from these techniques. The flexibility of the digital solution enables oblique, terrestrial and vertical photographs to be used and this increases the number of potential applications still further.

Universities now have to seek an increasing percentage of research funds independently of government grants. In an attempt to raise revenue, City University established the Engineering Photogrammetry Unit (EPU) so that capital can be generated by applying photogrammetric expertise in the commercial arena. One of the unique services that EPU has been able to offer is the ability to provide metric data from unconventional imagery and many commercial contracts have now been carried out.

Direct Use of the Method

Several contracts have made direct use of the archival photogrammetric technique and have required no modification of the original software. National Power has been assisted on two occasions.

Mapping tree canopies. In the first instance, National Power required data to represent tree canopies over an area, 100km² in extent, of rolling mixed arable and forested uplands. Finance for the project was strictly limited and new aerial photography could not be justified. Recent photography of the site was available but consisted of a series of oblique colour photographs acquired with a hand held Hasselblad small format camera. These photographs had been taken through the canopy of a helicopter flying at 1600 m and were not ideal from a photogrammetric point of view. Three dimensional data were required in order to represent the boundaries of all wooded areas, with tree heights determined to a precision of ± 0.5 m. EPU decided that such "tree envelopes" could be derived, to a level of precision acceptable to the client, using even this unfavourable imagery. Plan and height control were derived from Ordnance Survey (OS) 1:10000 scale maps. Fourteen colour negatives were selected and both control points and additional pass points were measured. All measured data were processed using the suite of four programs and final interior and exterior orientations were derived using the self calibrating bundle adjustment. Initial processing revealed large residuals on some control co-ordinates, some exceeding 100 m in plan. It transpired that two different cameras had been used, with focal lengths of 52mm and 81mm. Once the photographs associated with these cameras had been identified and the data re-processed, residuals dropped to 5 m. These final residuals were within the judged precision of the control co-ordinates scaled from the OS plan.

Once the exterior orientation of all frames and a satisfactory calibration for each camera had been derived, it was possible to set up models on the IMA. Surprisingly, this entailed forcing Intergraph software to re-estimate the exterior orientation parameters derived previously, by constraining them with very small standard deviations. The effects of lens distortion were removed by incorporating a "Foreign distortion look-up table" (DLUT). The DLUT consists of a grid of image co-ordinate corrections which covers the whole format of the photograph. Elements of the DLUT were derived from the estimated parameters of the even powered polynomial used to model radial lens distortion. Tree envelopes could then be digitised and these data were stored in an Intergraph design file for use with National Power's Intergraph system.

Modelling a power station. In the second contract, National Power required a three dimensional model of Fawley power station. Oblique aerial photographs had been acquired with a hand held Rolleimetric 6006 small format camera on return from a previous contract (Fig. 1). Twelve photographs were taken whilst the helicopter circled the power station, producing an object and photographic geometry which is ideal for self calibration procedures (Granshaw, 1980). A control survey was carried out on site, in which the three dimensional co-ordinates of 18 prominent natural points were determined to a precision of ± 0.05 m. The image positions of these control points and some additional pass points were measured using the IMA. Control and image co-ordinates were then processed using the archival photogrammetric technique and both interior and exterior orientation parameters derived. It was then possible to set up models on the IMA using the procedures discussed in relation to the tree canopy contract.



FIG. 1. Hand held small format photograph of power station.

Final data acquisition required measuring the three dimensional co-ordinates of many thousands of new points. These were used to produce a full three dimensional representation of the power station and a digital terrain model of the surrounding area. Substantial editing of these data was required in order to produce a fully surfaced three dimensional model of the site. The use of elements which possess the surface characteristic enables realistic rendered images to be produced (Fig. 2).

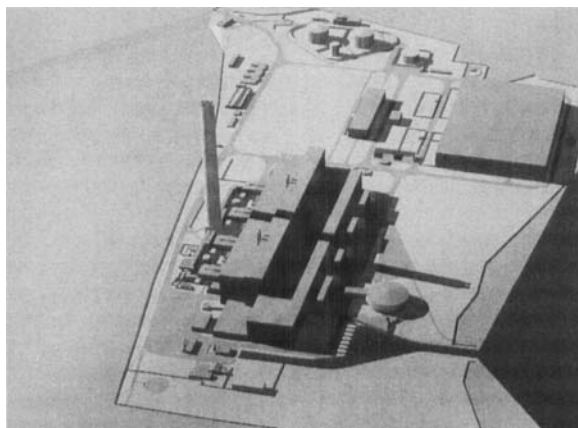


FIG. 2. Fully surfaced three dimensional model of power station.

Plotting ceiling cracks. On a smaller scale, EPU has assisted the City Engineer at the Corporation of London to assess the impact of tunnelling works on the Mansion House ballroom ceiling. The tunnelling is associated with the extension of the Docklands Light Railway at Bank Underground Station in central London.

Using four small format photographs originally acquired in 1986 for purely qualitative purposes (Fig. 3), EPU was able to establish the interior and exterior orientation parameters associated with all photographs. Although the control co-ordinates of prominent natural features were derived by field survey, it was the original survey measurements which provided the control data used in the final self calibrating bundle adjustment. An estimation composed of both survey and image measurements is known as a "simultaneous" solution and is preferred because the full stochastic properties of all measurements are taken into account. Models were established on the IMA and the Corporation of London was provided with a plan showing the number and distribution of ceiling cracks in 1986. This plan has been compared with a similar plot measured using Zeiss UMK photography obtained in May 1990. The ability to derive spatial data from historical photographs has been particularly important in this instance. The older photography was acquired prior to any tunnelling works and has recorded the state of the ceiling at that time. The influence of tunnelling on the ceiling has been determined directly.



FIG. 3. The Mansion House ballroom. *Royal Commission on the Historical Monuments of England.*

Mapping a peat bog. The Nature Conservancy Council (NCC) has accumulated a large archive of colour small format photography and also possesses an Intergraph InterMap Analytic. In a recent contract, EPU demonstrated that their archive can be considered suitable for measurement by carrying out a pilot project in which some of their archive material was used.

The test example consisted of a series of vertical colour small format

photographs covering an area of collapsed peat bog in Scotland. Control was provided by NCC surveyors who obtained the three dimensional co-ordinates of ten natural features visible on the photography. This material was restituted successfully using the archival photogrammetric technique and models were established on the IMA. The NCC will now be able to perform their own restitutions, although access to a proprietary self calibrating bundle adjustment will be required.

Further Development

Development of City University's version of the self calibrating bundle adjustment has continued since its original inception, particularly following the return of J. Clark to the department. He has rewritten the program in C and renamed it GAP, standing for "General Adjustment Program". The program makes more efficient use of both memory and CPU and includes several other substantial improvements. Many of these developments have been prompted by and are closely associated with the demands of contract work.

Block variancey. It is now possible to identify "blocks" of photographs which have been acquired with differing cameras. Previous "block invariancey" required those data associated with the tree height contract for National Power to be split and processed independently, according to camera focal length. The program is now block variant and one combined estimation can now be used in which an independent and differing set of interior orientation parameters can be derived for various blocks of photographs or cameras.

Data snooping. Another important addition has been data snooping which assists in the detection of gross errors in both photoco-ordinates and survey measurements (Baarda, 1968). This entails evaluation of the τ -test statistic derived using the standard error of the estimated residual and each measurement residual (Cooper and Cross, 1988). If this value is greater than a critical value derived from the F distribution, at a specified level of significance, the measurement is flagged. In this way potential gross errors are identified and the photogrammetrist can decide whether there is justification to remove the suspect measurement. Unfortunately a major problem with data snooping procedures is the underlying assumption that only one gross error exists and that the selected functional model is correct. If there are either several gross errors or if the selected interior orientation parameters are unsuitable to model the system, it becomes extremely difficult to isolate the various error sources.

Video imagery. One particular contract required urgent modifications to GAP. EPU had been asked by the Metropolitan Police Flying Squad to estimate heights of bank robbers from limited security imagery recorded by two video cameras. This type of imagery proved quite difficult to use for a variety of reasons. Image quality was extremely poor because the video tape had been continually used and reused for many months prior to the actual robbery. The number of well identifiable fixed points which could serve as suitable control points was extremely limited. Although overlapping images were provided by the two video cameras, stereocover was unavailable because successive images from the two cameras were time sequenced. Of principal interest to this paper was the source of systematic error detected with the video imagery. The presence of this error source required a major modification to the self calibrating bundle adjustment. When image co-ordinates were processed with the original self calibrating bundle adjustment, very large image residuals were detected. The pattern of these suggested that there were substantial differences in the x , y image scale, probably attributable to differences in time base during the original recording of the image onto videotape. The GAP program was modified to derive an optional scale factor between x and y image co-ordinates which reduced all residuals substantially. Further details concerning this particular contract cannot be divulged as the case is awaiting trial.

User manual. An additional item which has been developed in parallel to GAP, although perhaps lagging slightly behind, has been a comprehensive user manual describing the new software and usage.

CONCLUSION

The routines encompassed within the archival photogrammetric technique have proved particularly effective for dealing with historical photographs. Since initial development, the self calibrating bundle adjustment has become the most important single tool used by the Engineering Photogrammetry Unit. There seems to be an area of commercial work which could be described as “special” or “scientific” in which the program is proving particularly versatile. Use of the program and expertise in these special areas of activity should sustain the required commercial ambitions of university departments without encroaching on the work of wholly commercial photogrammetrists.

The EPU at City University is keen to develop photogrammetric expertise and to make use of the photographic archives of the UK in a quantitative way. The greater the number of applications and users, the greater the likelihood that this particular resource will be maintained.

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Résumé

On analyse rapidement les bases des techniques d'archivage photogrammétrique. On présente des applications de cette méthode à la fois dans le domaine de la recherche et pour des contrats commerciaux; ces applications ont donné lieu à de nouveaux développements de la méthode.

Zusammenfassung

Die Grundlagen der photogrammetrischen Archivierung werden kurz dargestellt. Anwendungen des Verfahrens, sowohl bei der Forschung als auch bei kommerziellen Verträgen werden beschrieben und beeinflussen die Weiterentwicklung der Methode.