OPTIMIZATION OF NON-METRIC ANALYTICAL CLOSE-RANGE PHOTOGRAMMETRIC NETWORKS

H. M. Karara & L.-C. Chen
University of Illinois at Urbana-Champaign
Urbana, IL 61801
U.S.A.
Commission V

ABSTRACT

In a given close-range photogrammetric project, various combinations of data acquisition and data reduction methods yield results that meet different levels of accuracy requirements. It is the responsibility of the photogrammetric engineer to seek out the optimal combination according to the goals, objectives and economics of the project. This study concentrates on non-metric cameras and investigates two representative photographic systems. The various alternatives to object-space control are analyzed. The sequential, simultaneous, and hybrid approaches to data reduction will be studied and analyzed, and various solutions within each approach will be compared. Improving the accuracy using the "multiple approach" will be investigated. The DLT approach will be used as an initial step in a modular, fully integrated data reduction scheme based on spatial coordinates and additional parameters to give higher reliability, greater accuracy and lower cost. The use of microcomputers for this solution will be investigated.

INTRODUCTION

This is a summary report on an ongoing investigation at the University of Illinois at Urbana-Champaign on optimization of non-metric analytical close-range photogrammetric networks. Two cameras were chosen to represent the gamut of non-metric cameras currently in use in photogrammetric engineering: Hasselblad 500-C and Cannon AF 35 ML. Results obtained using these two cameras are to be compared to results obtained using a Wild P31 Universal Terrestrial Camera.

A few years ago, analogue methods were paramount in close-range photogrammetry (CRP) and special cameras and stereoplotters were utilized. This put rather severe limitations on the configuration of the data acquisition systems and thus on the attainable accuracy of CRP. The current use of the analytical approaches in data reduction permits considerably more freedom in the choice of the configuration of photography and object-space control parameters as compared to the analogue approach, allows higher accuracy and more reliability, and widens the scope of application of CRP.

This evolution has also resulted in the wide acceptance of non-metric cameras as data acquisition systems along with metric cameras. Flexibility in focussing and relatively low prices compared to metric cameras, are the main features which led to the ever increasing use of non-metric cameras in close-range photogrammetry. In spite of the significant advances in design and construction concepts of close-range metric cameras in the past two decades, almost no progress has been made to rectify the drawbacks of the rigid limits of focussing and the frequently prohibitive prices of metric cameras. Furthermore, it has been demonstrated both theoretically and experimentally, that non-metric cameras can yield moderately high relative accuracies (in the range of 1:6,000 to 1:10,000 or better) when used in conjunction with suitable analytical data reduction schemes of increasing sophistication.

In a given CRP project, various combinations of data acquisition and data reduction methods yield results that meet various levels of accuracy requirements. It is the responsibility of the photogrammetric engineer to seek out the optimum combination of systems and subsystems according to the goals, objectives, and economic considerations of the project. Before one can optimize a system, the interactions of the various components of the different subsystems should be investigated.

THE DLT APPROACH

The Direct Linear Transformation (DLT) approach, developed at the University of Illinois (Abdel-Aziz & Karara, 1971), opened the door for the use of non-metric cameras in close-range photogrammetric projects. The DLT is a sequential-type solution in which the innovation is the concept of direct transformation from comparator coordinates into object-space coordinates, thus bypassing the traditional intermediate step of transforming image coordinates from a comparator coordinate system into a photographic coordinate system. The DLT solution needs no initial approximations for the unknowns, thus a solution is obtained by DLT even in cases where a simultaneous-type solution fails to converge due to the lack of reasonable initial approximations for the unknown parameters. No iterations are normally used in the DLT solution, and fiducial marks are not needed. Furthermore, the computer execution time and the computer memory needed in DLT are less than those in the simultaneous-type solutions. In the DLT solution, the eleven transformation parameters L_1-L_{11} are considered independent. Bopp & Krauss (1978) developed an exact solution to the DLT basic egnations in which they took into account the dependence among these eleven parameters and the nine parameters necessary to represent a "perfect camera". Two constraints are incorporated in the solution as additional observations with zero variance. In the presence of a healthy degree of redundancy in object-space control, the DLT and the so-called "11 Parameter Solution" of Bopp & Krauss become equivalent for all practical purposes as indicated by Fraser (1982) and as found experimentally by numerous other colleagues in a number of research centers, including the University of Illinois.

Over the years, a number of modifications have been introduced in the DLT solution improving its accuracy slightly. As an example, the Dell Foster Company in San Antonio, TX, incorporated a nonlinear solution of the DLT equations in the software of its MACO 35/70 analytical plotter (McGlone, 1984). A few modified versions of the DLT solution have been worked out by a number of consultant engineers, and are currently commercially available.

While the DLT approach leads to a reduction of the cost of data acquisition system by using non-metric cameras, and the cost of data reduction by using the DLT algorithm, it should be noted that measuring the "comparator coordinates" need not be done always on an expensive stereo- or monocomparator. For example, Welch and Jordan (1983-a) used positive film enlargements of 35mm negatives, measured point coordinates by means of a cartographic digitizer, and obtained accuracy levels completely acceptable to their project requirements.

The incorporation of plumbline distances of known X&Y coordinates as additional parameters for on-the-job calibration is currently under investigation and the results seem to be promising.

Because of the simplicity of the DLT approach, it has and continues to be extensively used in non-topographic photogrammetry. A glance through the Biostereometrics '82 proceedings (Herron, 1983) indicates how popular DLT has become in the fields of Biostereometrics. On the other hand, the DLT solution is sensitive to the configuration of the object-space control, and extra care should be taken to incorporate as much deviation from the planar configuration as depth of field considerations permit.

The achievable relative accuracy in recent projects using the above stated minor modifications in DLT is reported to be in the range of 1:6,000 to 1:7,000. This is acceptable in many fields of application.

MODERATE IMPROVEMENT OF ACCURACY

If it is desired to moderately improve the relative accuracy (say up to the range of 1;8,000 → 1:9,000 or better), a second sequential solution is to be undertaken. In this second stage, the adjustment incorporates nine independent transformation coefficients whose initial values are obtained from the DLT solution. A number of plumbline distances with known X,Y positions are to be used as additional parameters to compensate for the incomplete calibration of the data acquisition system. The systematic image errors (lens distortions and film deformation) are compensated by means of spherical harmonics (El-Hakim & Faig, 1977).

FURTHER IMPROVEMENT OF ACCURACY

If it is desired to improve the relative accuracy of DLT significantly (say up to 1:10,000 or better), then the DLT is to be used as a "front end" to find initial values for a bundle adjustment solution, and the aforementioned second stage of adjustment bypassed. A schematic flow diagram for this multi-stage adjustment is given in figures 1. In the flow diagram, the following symbols are used: D: distance from a representative (average) point to the photographic center of projection,

$\sigma = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2}$ = standard deviation of the spatial position of the representative point, and

ε = relative accuracy requirement.

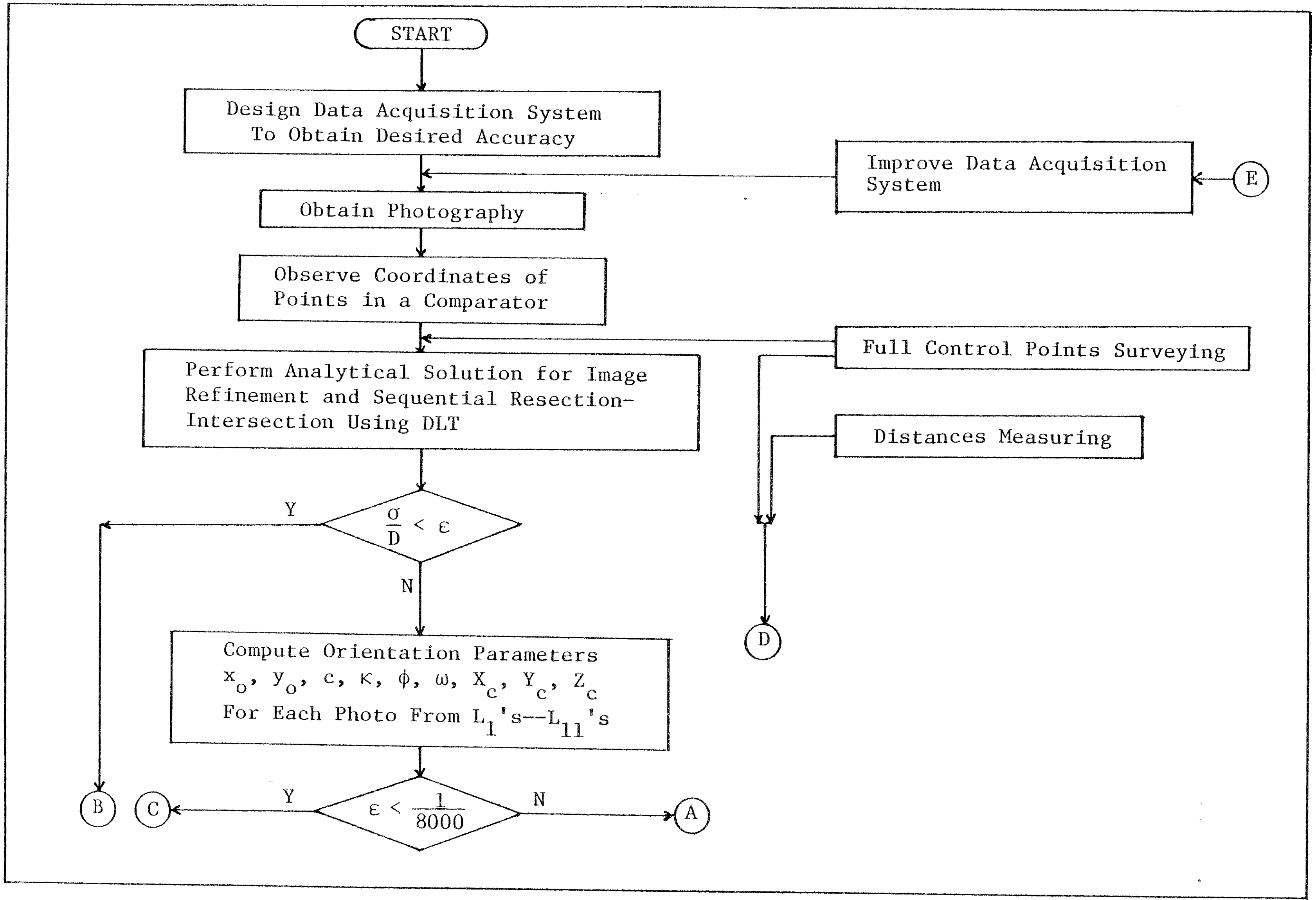

Fig. 1-a. Schematic Flow Diagram for Multi-Stage Adjustment. (continued on next page)

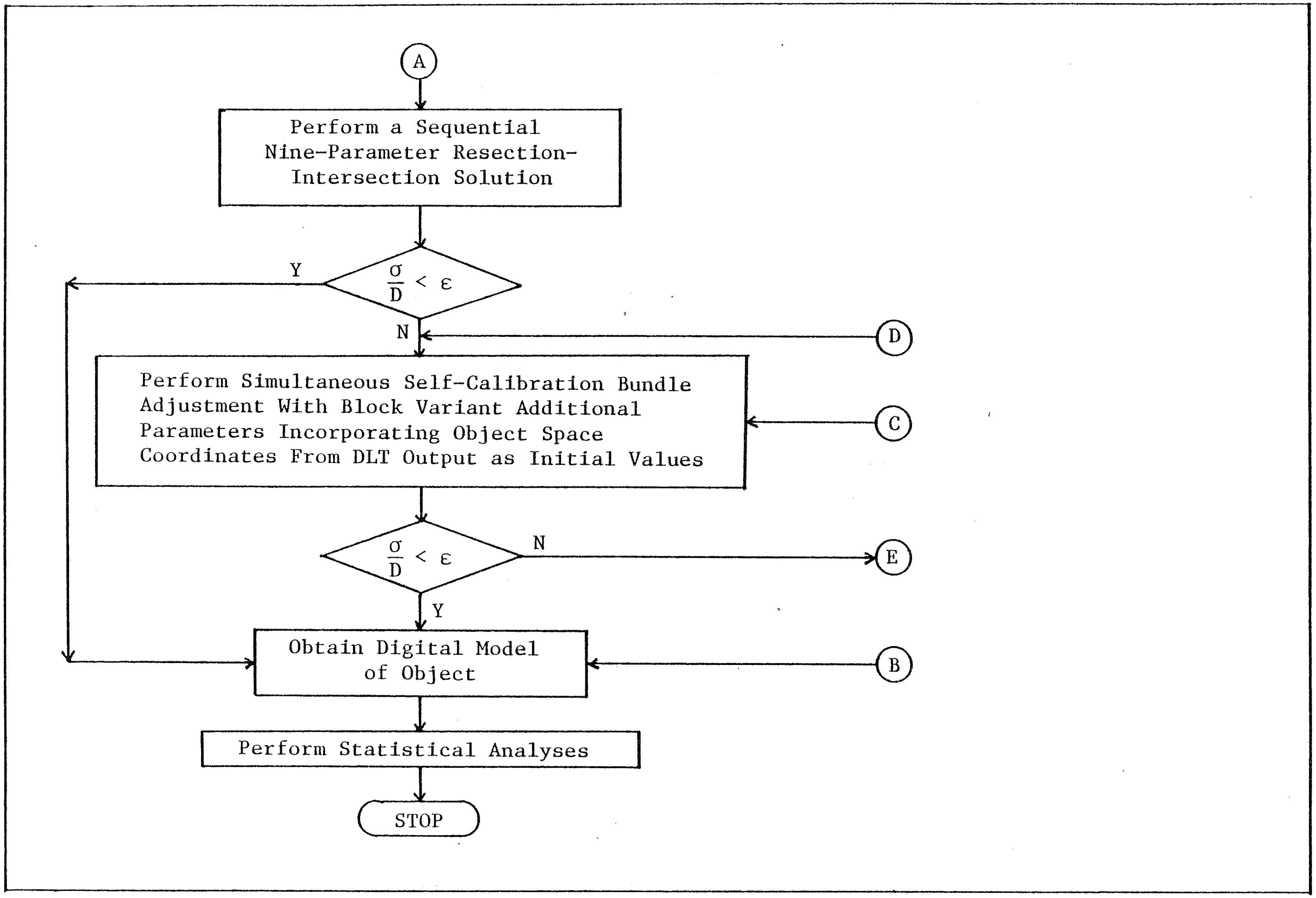

Fig. 1-b. Schematic Flow Diagram for Multi-Stage Adjustment.

The algorithm will be patterned after that of computer program GEBAT (El-Hakim, 1982), with arbitrarily oriented distances incorporated to compensate for systematic errors caused by incomplete calibrations of the data acquisition system. The system uses an extended bundle adjustment solution and a sophisticated least squares algorithm for gross error detection, localization and elimination. The technique of self calibration is planned to be incorporated in the solution. To further improve the accuracy, the multi-approach introduced by Hottier (1976) and expanded by Torlegård (1981) will be incorporated in the solution. Harmonic functions will be used to correct for lens distortions and film deformation. In short, every feasible technique will be incorporated in the solution in an effort to enable the bundle adjustment approach its full theoretical accuracy potential using non-metric cameras.

OPTIMIZATION

A procedure is currently under study for the selection of the optimal approach based on studies of the interactions of accuracy and economic considerations, under different configurations of data acquisition systems, additional parameters, object-space control and data-reduction systems. The approach used by Marzan and Karara (1976) is being used as the point of beginning of this effort.

MINICOMPUTERS

A feasibility study on the use of microcomputers for data reduction of the system under study will be performed. The combination of non-metric cameras and minicomputers seem to be emerging as a strong trend in close-range photogrammetry. It is evident that microcomputers are being applied to a variety of photogrammetric problems such as image coordinate refinement, numerical orientation, and aerotriangulation adjustments. At present (1984) most systems employ 8-bit microcomputers with 64K RAM or less and utilize software written in the BASIC programming language (Welch & Jordan, 1983-b). With the recent introduction of 16-bit microcomparators with 256K RAM, more complex computational tasks are performed. A case in point is Geodetic Services' STARS system (Brown, 1982) which employs a WICAT microcomputer and FORTRAN programs to perform fully analytical triangulation with as many as 24 close-range photographs.

CONCLUDING REMARKS

It is fully expected that the data reduction system currently under development will maintain the simplicity, flexibility, and popularity of the original DLT solution. Its modular structure is intended to enable it to meet accuracy requirements at various levels. Thus it is hopefully anticipated that this feature will add to the popularity, universality and reliability to the DLT and DLT-type solutions.

It should be noted that the accuracy levels mentioned in this paper were extracted from published and unpublished experimental data provided by colleagues and research institutes throughout the world, including some of our own experiments. In a follow-up paper, full data on the finalized system and updated accuracy levels will be included.

REFERENCES

-Abdel-Aziz, Y. I. and Karara, H. M. (1971). "Direct Linear Transformation from Comparator Coordinates into Object-Space Coordinates," Proc. ASP/UI Symposium on Close-Range Photogrammetry, Urbana, IL.

-Ackermann, F. (1980). "Blockadjustment with Additional Parameters," International Archives of Photogrammetry, Vol. 13, Part B-3, Hamburg.

-American Society of Photogrammetry (1979). Handbook of Non-Topographic Photogrammetry (H. M. Karara, Editor), Falls Church, VA.

-American Society of Photogrammetry (1980). "Manual of Photogrammetry," Fourth Edition (C. S. Slama, Editor), Falls Church, VA.

-Bopp, H. and Krauss H. (1978). "Extension of the 11-Parameter Solution for on-the-job Calibration of Non-Metric Cameras." International Archives of Photogrammetry, Vol. 22, Part 5, Stockholm.

-Brown, D. C. (1982). "STARS -- (Simultaneous Triangulation and Resection System), A Turnkey System for Close-Range Photogrammetry." International Archives of Photogrammetry, Vol. 24, Part 5/1, York.

-Earls, C. J. (1983). "Accuracy Potential of a System for Analytical Close-Range Photogrammetry," Photogrammetric Record, Vol. 11, No. 62.

-El-Hakim, S. F. and Faig, W. (1977). "Compensation of Systematic Image Errors Using Spherical Harmonics," Proceedings, ASP Fall Technical Meeting, Little Rock, Arkansas.

-El-Hakim, S. F. (1982). "The General Bundle Adjustment Triangulation (GEBAT) System -- Theory and Applications," National Research Council of Canada, Publication NRCC 20539, Ottawa.

-Faig, W. and El-Hakim, S. F. (1982). "The Use of Distances as Object-Space Control in Close-Range Photogrammetry," International Archives of Photogrammetry, Vol. 24, Part 5/1, York.

-Fraser, C. S. (1982), "On the Use of Non-Metric Cameras in Analytical Close-Range Photogrammetry," The Canadian Surveyor, Vol. 36, No. 3.

-Gruen, A. (1978), "Accuracy, Reliability and Statistics in Close-Range Photogrammetry," International Archives of Photogrammetry, Vol. 22, Part 5, Stockholm.

-Herron, R. E. (Editor). (1983), "Biostereometrics '82," Proc. SPIE 361, Bellingham, Washington.

-Hottier, Ph. (1976), "Accuracy of Close-Range Analytical Restitution: Practical Experiments and Prediction," Photogrammetric Engineering and Remote Sensing, Vol. 42, No. 3.

-Marzan, G. T. and Karara, H. M. (1976), "Rational Design of Close-Range Photogrammetry," Civil Engineering Studies, Photogrammetry Series 43, University of Illinois, Urbana.

-McGlone, J. C. (1984), "Use of the MACO 35/70 in Close-Range Photogrammetry," International Archives of Photogrammetry, Vol. 24, Part B-5, Rio de Janiero.

-Torlegård, K. (1981), "Accuracy Improvement in Close-Range Photogrammetry," Heft 5 der Schriftenreihe der Wissenschaftlich Studienganges Vermessingswesen an der Hochschule der Bundeswehr München.

-Welch, R. and Jordan, T. R. (1983-a), "Analytical Non-Metric Close-Range Photogrammetry for Monitoring Stream Channel Erosion," Photogrammetric Engineering & Remote Sensing, Vol. 49, No. 3.

-Welch, R. and Jordan, T. R. (1983-b), "Microcomputer-Based Photogrammetry," Proceedings, ASP Annual Convention, Washington, D.C.