Contract Issues for GPS/Photogrammetry: A Management Perspective

Abstract
There has been a tremendous impact on the surveying and mapping industry from science and technology over the last 30 years. The challenge facing the private sector is how to integrate new technology successfully into the production environment. In parallel, the goal of public organizations is similar but has been extended to reflect the use of new technology in specifications for contract work. Individually, the fields of GPS and photogrammetry each require a sound level of understanding to be successfully employed. Collectively, the level of understanding required to become operational in "Photo/Geodesy" is even greater. The Surveys and Mapping Section of Ontario Hydro has been actively investigating advances in both disciplines. Our goal is to establish production specifications which can serve as the basis for contract negotiations and contract monitoring. This paper reflects the background and experiences that have gone into the creation of a contract outline for GPS/photogrammetry at Ontario Hydro.

Introduction
In the opening decade of this century, Ontario Hydro was created by the province of Ontario, Canada, for two reasons: first, to establish public power in order to allow the province's economy to grow, and second, to bring reliable and affordable electricity to the people of the province. In the 86 years since, Hydro's basic mission of reliable power at cost has remained the same, but how that mission is accomplished has evolved in many ways in response to the changing social, governmental, economic, and technological priorities.

Functionally, the traditional role of "Surveys and Mapping" has been to perform engineering surveys to acquire data for the design and construction of major transmission lines and to conduct legal surveys for the acquisition of rights in land. The broadening of our mandate in the last few years has provided an expanded role in the development and integration of new technology to enhance the production environment. The reorganization of Surveys and Mapping as a section under the Technical Services Department — Lines Strategic Business Unit, has further emphasized our role in coordinating technology transfer.

The "right-sizing" of public organizations in the province over the last 10 years has created a shift from "make" to "buy." The Surveys and Mapping Section has undergone a significant reduction in staff over this time period and now contracts more than 50 percent of all work including 100 percent of all photogrammetric compilation. In the past five years, Surveys and Mapping has let over 1200 contracts, the management of which has been an iterative process that has changed significantly with time and experience. One thing is clear; the key to a successful contract is a clear definition and understanding of the products required and the roles of the principles involved.

The anticipated work load for Ontario Hydro over the next few years will involve the construction of new transmission lines and the refurbishment of old ones. Each of these ventures require a variety of spatial information products. A significant portion of future work will be conducted in remote areas of northern and central Ontario. There are numerous problems in conducting a mapping project in these areas; for example, accessability, sensitivity to Aboriginal lands, terrain, and weather conditions, all can add significantly to the project cost. The integration of GPS/photogrammetry could significantly reduce the costs of the mapping component for many of our projects, especially for projects in remote sectors of the province. In order for Ontario Hydro to fully capitalize on this technology, the necessary infrastructure must be in place (technical and administrative) to ensure a successful operation.

Addressing Technology
The goal of technical development within the Surveys and Mapping Section at Ontario Hydro has been to monitor the research being conducted in geodetic science, surveying, and remote sensing, and assess the applicability to our information requirements. It has been found that our participation in professional organizations and technical committees in both the United States and Canada has been extremely beneficial in remaining current with developments in the industry and for communicating with individuals and organizations with similar goals. If a technology is found to be viable, the next step involves integrating that technology into the production environment. The transition from theory to practice is the most difficult step to achieve.

Although not a mainstream practice in industry, GPS/photogrammetry is progressing rapidly and its implementation is the priority of many mapping organizations world wide. Unfortunately, like most developments in photogrammetry, the time gap between "invention" and "practice" has been significant. As discussed by Schenk (1990), the transition from analog to analytical photogrammetry has taken over 30 years and is still not complete. A similar delay is anticipated when predicting the impact that digital photogrammetry will have on the industry. Notwithstanding the developments in other areas of the science, in order to become operational in GPS/photogrammetry, one must become literate with each of the disciplines before applying the two in tandem.

As stated, the majority of effort in photogrammetry during the last decade has focused on the transition from analog

Photogrammetric Engineering & Remote Sensing,
Vol. 59, No. 11, November 1993, pp. 1637–1641.

0099-1112/93/5911–1637$03.00/0

Robert L. Tudhope
Surveys and Mapping Coordination Section, Technical Services Department, Ontario Hydro, 393 University Avenue - D12 D06, Toronto, Ontario M5G 2L6, Canada.

to analytical and the development of "digital" mapping techniques. Because Ontario Hydro contracts for the majority of it's mapping work, our contract specifications have gone through numerous refinements to reflect the changes in practice. The concept of "System Calibration" has been underlying the evolution of our mapping specifications and quality control procedures during the last few years. Essentially, we are trying to ensure the spatial integrity of the coordinates and the mapping products we generate.

The concept of "Measurement System Calibration" was proposed by Churchill Eisenhart (1963) of the United States Bureau of Standards and provides a rational approach to the assessment of any measurement system in terms of accuracy. The application of Eisenhart's concept to the photogrammetric measurement problem has been discussed by Merchant (1972), Marchant *et al.* (1990), and Lapine (1990). Ontario Hydro's contract specifications for photogrammetric mapping try to ensure the use of analytical techniques throughout the production process, and independent "audit points" are required on all our mapping projects. Ontario Hydro will continue to improve these specifications where appropriate and as technology dictates.

The Surveys and Mapping Section has been following the development of the Global Positioning System (GPS) for some time, and, like others in the industry, recognized the tremendous impact GPS would have on our business. However, it is one thing to admire a technology and quite another to commit to investing in it. The cost justification is not as simple as required for the purchase of an EDM or Total Station. Consequently, in the spring of 1989, the Surveys and Mapping Section prepared a Business Plan to develop in-house capabilities to perform GPS surveys. The culmination of the three-year plan has provided Ontario Hydro with the capability of conducting GPS surveys for production mapping and control survey projects, and for auditing contractor's returns.

The first step in the preparation of our Business Plan was to make an assessment of the future work load. All indications pointed to the fact that the percentage of contract work would increase and that there would be no corresponding increase in staff. In reviewing how we would accomplish our work, it was clear that the use of GPS technologies would go a long way in helping address our project work—both through its use by external contractors and for our in-house quality control procedures. The next step was to initiate the budget process, and, in the fall of 1989, the Technical Development Group in Surveys and Mapping recommended that the three-year budget plan provide for the purchase of three GPS receivers and the required training for two five-person crews.

Upon receiving the necessary financial approval, Surveys and Mapping took possession of two geodetic receivers and one portable unit. In order to get our crews "up to speed" with the equipment and technology, we solicited the help of an external consulting team that had extensive experience in GPS surveys. The training phase consisted of both classroom and field trials. The classroom work involved a review of Geodesy and Adjustment Computations theory along with a detailed review of the specifications for the planning, execution, and reduction of GPS surveys. The field training consisted of numerous micro surveys using both static and kinematic techniques. The culmination of the field training was a 2-week "survey camp" in which the GPS work carried out by our field crews was bench-marked against a "GPS validation network." The field camp was tremendously successful. In hindsight, the key to the successful implementation of our plan has been the commitment of budget for training and development.

In following the developments of GPS/photogrammetry, we were encouraged by the results discussed by Lucas (1987) and the ground breaking efforts of Lapine (1990). In the hope of gaining experience in GPS/photogrammetry, Ontario Hydro expanded the scope of a mapping project located northwest of Thunder Bay, Ontario, to assess the use of airborne GPS, lasers, and multispectral imagery to develop ground terrain. The results are detailed in Tudhope (1991). Despite only achieving 0.75 to 1.0-m positional accuracy of the image platform, the two basic conclusions were that it was possible to achieve the mapping accuracies required for project work with a significant reduction in ground control, and that the potential of positioning the platform of any airborne sensor would significantly enhance the utility of the data set.

Continuing our development work, in October 1991, Ontario Hydro, in a joint venture with the Canada Centre for Remote Sensing, Innotech Aviation Ltd., National Oceanic and Atmospheric Administration, Ohio Department of Transportation, and Topo Photo Inc, set out to calibrate an RC-10 aerial camera and to assess the accuracy of the MEIS II stereo line imaging scanner (Till *et al.*, 1986). Aerial photography and imagery were collected over the Ohio calibration range at 1:10,000 scale (RC-10) and 0.5-m pixel resolution (MEIS) respectively, under kinematic GPS control. Although the results are still being compiled, the tests show that it is possible to position the airborne platform to less than 10 cm, and that "System Calibration" is a necessity no matter what the imaging platform or medium of data capture.

Contract Issues

During the last few years, the Surveys and Mapping Section moved away from awarding contracts solely to lowest tender and adopted a proposal system where final contract award would be based on merit. The cost component would then be only one of the contributing factors to the proposal evaluation. In adopting this approach, Surveys and Mapping has found that the quality of the mapping products received has greatly increased. However, a "Request for Proposal" (RFP) project specification, which serves as the foundation of the project contract, must be quite rigorous and complete.

Our experience with GPS/photogrammetry has lead to the conclusion that, if we were to enter into a contract arrangement for the procurement of such services, the guidelines and specifications would have to address a significant number of issues. It has also been realized that there would have to be as many "checks and balances" as possible built into the process to ensure success. In developing a contract outline, the work completed by Lapine (1990) and the experience of the Ohio Calibration Project, served as a model.

In initiating a mapping project, the first two issues to address are the definition of product required and the accuracies associated with these products. Next, it will be necessary to assess whether the option for GPS/photogrammetry is to be considered or whether "traditional" photogrammetric approaches would be better suited. For example, some transmission line projects require a framework of geodetic control for legal and construction purposes at a density greater than required for photo control. Assuming the use of GPS/photogrammetry techniques are approved, the "framing" of the project specification begins.

Pre-Qualification

Ontario Hydro has been approached by a number of firms indicating that they are capable of performing aerial surveys by

Table 1. Issues for Pre-Qualification of GPS/Photogrammetric Firms

AIRCRAFT SYSTEM
* Operational Requirements/ Limitations
* On-board Nav System Performance
* Pressurized vs Non-Pressurized Cabin
GPS DATA COLLECTION SYSTEM
* GPS Receiver Make and Performance
* On-board Data Logging/ Event Record
* Make and Performance of Antenna
Location - Aircraft & Camera
Pre-Calibration of Phase Center
Pre-Amp Location - S/N Ratio
Spatial Offset to Exposure Station
* Initialization Process (Ambiguity Res)
IMAGE COLLECTION SYSTEM
* Aerial Camera and Accessories
* Calibration of Interior Orientation
* ID and Control of Timing Biases
* Image Motion Compensation
* Camera Mount Controls
* Film Type and Scale
IMAGE PROCESS/MEASUREMENT
* Distortion - Processing and Printing
* Analytical Plotter Calibration
* Analysis Software/Independent Check
CALIBRATION RANGE
* Control Field Accuracy
* Target Design/Density/Optimum Scale
POST PROCESSING MODEL
* GPS Data Reduction Software(s)
* Integer Ambiguity Resolution
* Antenna at Exposure Interpolation
* Block Adjustment Software(s)
Direct Observations
Interior/Exterior Orientation
A-Priori Weighting Schemes
Use of Auxiliary Parameters
* Accuracy Assessment of Measurement System

GPS/photogrammetry. Our response has been that they must submit the results of their System Calibration for our review before being pre-qualified as operational. Issues for discussion in a review of contractor's qualifications are summarized in Table 1. Essentially, a detailed description of the airborne photogrammetric measurement system, the post processing model, the model for integration of the direct observations into the mapping equation, and a complete documentation of all field test results is required.

The importance of System Calibration in this context cannot be stressed enough, as there are many potential sources of systematic error. We believe that this is the key to a successful operation. As discussed by Lapine (1990), "... The kinematic positioning of the aircraft yields a position for the airborne GPS antenna on a fixed time interval throughout the photo mission. It is necessary to consider several systematic errors which would otherwise contaminate the transformation of the antenna position to the exposure station position. The systematic errors include timing bias between the GPS navigation information and camera exposure station time tags, timing bias between shutter pulse and actual lens opening, bias in the determination of the spatial offsets between the GPS antenna and camera reference frame, and bias in the interpolation model used to compute the antenna position at the moment of exposure."

Continuing, Lapine also states that, "... In addition to the biases between GPS and the exposure station, aircraft induced biases caused by the optical flat between the camera compartment and exterior of the fuselage, atmospheric refraction, interior camera orientation, and film deformation must be identified and modeled," As the potential exists for the propagation of all these errors into the final results, a discussion of their elimination or control is essential.

In terms of the GPS data collection system, the contractor should be required to outline the components of the system. The type of aircraft must be identified along with the range, performance, runway length requirements, and any performance limitations. The make, type, and location of GPS receivers must be identified along with the make, type, and location of the antenna. It is important to pre-calibrate the exact location of the phase center of the antenna. The process by which the location of the phase center is transferred to the ground during the initialization process must also be detailed.

A discussion of the image collection system should include the make, type, and calibration of the aerial camera, the effect that image motion compensation has on the timing events, camera accessories, the location and type of camera mount(s), calibration of the timing bias in the camera with respect to GPS time, and the process by which the spatial offsets from the camera to the phase center are determined. Some of the timing offsets are now addressed by the camera manufacturers; however, their control should still be acknowledged.

The post-processing model discussion must include the type of software(s) used to process the kinematic GPS survey data and a discussion of the verification of the integer cycle count. The model for determining the spatial location of the exposure stations should also be documented. Once the exposure station positions and associated accuracies have been determined, these direct observations must be included into the mapping equation. The type of bundle block adjustment used must be discussed, including any use of auxiliary parameters to address systematic errors, including "GPS Drift" (Ackermann, 1992).

An assessment of the performance of the airborne photogrammetric measurement system under GPS control requires that the system be bench-marked against a standard of higher accuracy. A discussion of this standard is required. If a targeted calibration range was used, then the history of the range and coordinate accuracies should be included. The reduction of the photogrammetric data involves stages of film processing and image mensuration. The identification and control of systematic errors in each of these stages is essential. The final comparison of the ground positions derived from GPS/photogrammetry to the "true values" will establish the accuracy threshold of the measurement system for operational work.

Project Specific Issues

There will always be issues which are specific to each individual project but which must be addressed in the project specifications. Some items for discussion are summarized in Table 2. Prior to the RFP stage, there must be an assessment as to the applicability of GPS/photogrammetry to the project requirements and the geographic location of the site. If uncertain, one can always entertain estimates for both the traditional approach and the GPS option in the RFP. If the GPS/photogrammetry option is approved, it must be assured that there is no deviation from the pre-qualified system during project operations.

It is essential to build as many checks and balances as possible into the approach. As described, Ontario Hydro require independent audit points on all mapping projects. However, the decision must be made as to whether the con-

TABLE 2. PROJECT ISSUES FOR CONTRACT SPECIFICATIONS

PROJECT SPECIFIC
* Definition of Mapping Requirement and Accuracies
* GPS Methodology Employed
* Deviation from Pre-Qualified Measurement System
* Proximity of Project Site to Airports
* Availability and Suitability of Airport
* Establishment of Airport Control and Baseline
* Number and Location of Signalized Ground Control
* Number and Location of "Audit Points"
* Flight Mission Design (Scale)
* GPS Window vs Photographic Window
* Submission of all Data Sets
* Accountability

tractor is permitted to conduct the mission with no ground control at all. It is our opinion that this is not a prudent procedure and some signalized control is required in the verification of the block adjustment and for establishing the relation to the local survey datum. The number and location of the control points can be negotiated.

As the majority of mapping done by Ontario Hydro is along a transmission corridor, the photo flight mission should be designed to provide for some redundancy. It has been demonstrated that two parallel overlapping strips provide for additional geometric strength in the determination of the camera orientation parameters. A decision has to be made as to whether photography for the entire corridor be collected this way or collected as single flight lines augmented with cross strips at select intervals for added geometric strength. The option is also available for multiple GPS antennas on the aircraft to solve for the orientation unknowns, a condition which may also ensure that continuous lock on the satellites is maintained.

The mapping accuracies required of the project will dictate whether sub-decimetre positioning of the airborne platform is even required. Therefore, one might propose that real time differential is more attractive than kinematic GPS, given the operational restrictions of a project. In order to address this issue, a threshold must be established, prior to the RFP, relating the accuracy requirements of the mapping to the GPS positioning technique permitted.

Although less of an issue as the satellite constellation increases, there are times when the ideal photographic window and the ideal GPS window do not coincide. In this case, do you concentrate on getting the photography done to specification and then acquire a second photo set under GPS control to be used for point transfer, or do you sacrifice some of the image quality to acquire a single photo set under GPS control? A decision must be made pre-mission as to the priority of the acquiring imagery according to specification.

Research being conducted into resolution of the integer ambiguity "on-the-fly" promises to make GPS/Photogrammetry operationally much easier. However, even if such technology were employed today, initialization of the roving platform would still be prudent, given that the determination of the cycle count is crucial to the overall solution of position. In addition, initialization may allow project operations to continue in the windows of minimal satellite constellation for 3D positioning. The methodology for initialization should be discussed, including the maximum distance allowable for the rover from the base station. Depending on the proximity of the runway to the project site, a base station may have to be established on-site during the mission.

During the data collection phase of the project, it is essential that presence at site be maintained by the contracting agency. Experience has shown that there are many decisions that must be made during operations, which usually can only be made on site. When the mission has been completed, the contracting agency should require that a copy of all original data sets be forwarded for independent processing in the event that any inconsistencies are discovered with the results.

Conclusions

The ultimate decision on how far to go in exercising control over the contractual process is the responsibility of the organization letting the contract. As a public organization, Ontario Hydro is looking for the best product available for the dollars spent. It is not prudent to rely totally on the contractor to ensure project success. We must be pro-active in our approach to ensure Total Quality Management (Jablonski, 1992). However, this requires that Ontario Hydro possesses the technical expertise to address the technology in practice. In the case of GPS/photogrammetry, it is essential to have both a working knowledge of the process and of the particular job on which the technology may be used.

Pre-qualification of a contractor will go a long way to ensuring a successful operation. However, it is also important to have defined the project information requirements and associated accuracies, before entertaining Request for Proposals. There should be as many checks as possible built into the contract—the role of "System Calibration" is essential in controlling the GPS/photogrammetric measurement system. Until the nature of the measurement system is understood in operation, there is no way for one to "dial in the appropriate setting" given the project requirements and accuracy specifications.

There are many who are waiting until GPS/photogrammetry becomes as simplified an operation as aerial photography: for some, this is good advice. However, our experience has shown that GPS/photogrammetry can be accomplished in an operational environment today. Given the competitiveness of the mapping industry, many organizations will be able to successfully meet the operational demands. Addressing the contract issues discussed will significantly increase the chances for project success. Without question, contract specifications will be refined as new developments in GPS and photogrammetry continue. However, Ontario Hydro is now willing to utilize this technology in production applications with confidence that our project information requirements and schedules will be met.

References

Ackermann, Fritz, 1992. Prospects of Kinematic GPS for Aerial Triangulation, *ITC Journal*, 1992-4, pp. 326–338.

Eisenhart, Churchill, 1963. Realistic Evaluation of the Precision and Accuracy of Instrument Calibration Systems, *Journal of Research of the National Bureau of Standards*, 67C(2):161–187.

Jablonski, Joseph R., 1992. *Implementing TQM - Competing in the Nineties through Total Quality Management, 2nd Edition*, Technical Management Consortium Inc., Albuquerque.

Lapine, Lewis A., 1990. *Analytical Calibration of the Airborne Photogrammetric System using A-Priori Knowledge of the Exposure Station Obtained from Kinematic Global Positioning System Techniques*, Phd Dissertation, The Ohio State University, Department of Geodetic Science and Surveying, Columbus, Ohio.

Lucas, James R., 1987. Aerotriangulation Without Ground Control, *Photogrammetric Engineering & Remote Sensing*, 53:311–314.

Merchant, Dean C., 1972. *Metric Calibration of the Aerial Photographic System by the Method of Mixed Ranges*, Report of the Department of Geodetic Science, No. 153, Columbus.

Merchant, Dean C., and Robert L. Tudhope, 1990. *Refinement of Analytical Photogrammetric Techniques for Application to Transportation Surveys*, The Ohio State University, Engineering Experiment Stations, Columbus.

Schenk, T., 1990. *The Effect of Digital Photogrammetry on Existing Photogrammetric Concepts, Procedures and Systems*, The Department of Geodetic Science and Surveying, The Ohio State University, Columbus.

Till, S.M., R.P. Gauthier, R.A. Neville, and, W.D. McColl, 1986. The MEIS II Pushbroom Imager - Four Years of Operation, *Progress in Imaging Sensors Proceedings, ISPRS Symposium*, Stuttgart, 1–5 September, (ESA SP-252, Nov 1986).

Tudhope, Robert L., 1991. Ontario Hydro Pilot Project Using Airborne GPS and Lasers to Develop Ground Terrain, *Proceedings from The Canadian Conference on GIS*, Ottawa, 18-21 March.

CALL FOR PAPERS
Special Issue on SOFTCOPY PHOTOGRAMMETRY

Photogrammetric Engineering and Remote Sensing

The American Society for Photogrammetry and Remote Sensing will publish a Softcopy Photogrammetry special issue of PERS in August 1994. This issue will contain commentaries, invited and contributed articles. Authors are especially encouraged to submit manuscripts on the following topics:

- Definition issues, functional requirements, and design considerations.
- Data issues, acquisition, volume, compression, visualization, and reduction.
- Digital orthophotography, production and use.
- Softcopy photogrammetry, image analysis, and GIS, the all-in-one system concept.
- Conversion of operational production systems into softcopy, requirements and implications.
- Standards, testing procedures, accuracy, performance, and system evaluation.
- Trends in technology, state-of-the-art, and future directions.

All manuscripts, including invited articles, will be peer reviewed in accordance with established ASPRS policy for publication in PE&RS. Authors who wish to contribute papers for this special issue are invited to mail five copies of their manuscript to:

Raad A. Saleh, ERSC, University of Wisconsin-Madison, 1225 West Dayton St., Madison, WI 53706; Phone: (608) 263-6584, fax: (608) 262-5964, internet: raad@cae.wisc.edu.

- All papers should conform to the submission standards in "Instructions to Authors" that appears monthly in PE&RS.
- Papers should be free from promoting a specific commercial product.
- Papers without funds for color printing may be subject to rejection by ASPRS Headquarters due to budget constraints.
- Cover image of the special issue may be selected from one of the submitted articles. To qualify, photos must be at least 9"X9" in size, and can be prints or transparencies.
- Electronic submission will be accepted using the above e-mail address, if the manuscript contains no graphics. However, final manuscripts must be in hardcopy, accompanied by DOS ASCII disk.
- All manuscripts must be received by 5 January 1994 in order to be considered for publication in this special issue.