Combined Control Densification and Mapping

Max M. Ethridge
NOAA, National Geodetic Survey, Office of Charting and Geodetic Services, National Ocean Service, Rockville, MD 20852

ABSTRACT: The need for horizontal control densification and large-scale base mapping over common ground areas is expected to escalate over the next few years in order to meet the requirements of the multipurpose cadastre. Control densification and mapping are now accomplished primarily by ground surveys and aerial photogrammetry, respectively. These are conventionally conducted as two separate and independent activities. The objective of this paper is to show that these two activities can be accomplished with photogrammetric techniques, using the same aerial photography. Procedures and specifications are presented which describe how third-order, class I control densification (1 part in 10,000) can be accomplished at one-mile spacing by photogeodesy and how a 1:4,800-scale orthophoto base map, which meets National Map Accuracy Standards (NMAS), can be produced from the same photography. Recommendations for the demonstration of this approach are also presented.

PROBLEM STATEMENT

IN MANY AREAS there is need for a more dense network of geodetic quality horizontal control to support local construction and development activities. At the same time, there is frequently an equally important need for large-scale mapping to support planning and development activities. The fulfillment of these two needs has traditionally been accomplished by two distinctly separate approaches—ground survey techniques and photogrammetric mapping.

Some control densification has been done by the National Ocean Service (NOS), and also by Duane Brown (1977), using photogrammetric techniques. The method is called photogeodesy because it produces geodetic quality positions by using photogrammetric techniques. However, if large-scale maps of densification areas are desired, they have to be obtained by a separate photogrammetric procedure using a different set of photographs taken at a larger scale. This approach is necessary because the resolution of the special NOS geodetic lens cone used to produce geodetic quality point positions is optimized for the specific wavelength of the geodetic targets and, therefore, does not have the resolution needed to support large-scale mapping from the photo scale (normally 1:24,000) used for photogeodesy.

The use of the two independent photogrammetric procedures described above to accomplish control densification and mapping is functional and effective, but it does require two different sets and scales of photographs. The obvious question follows. Is it possible through improvements in techniques or equipment to efficiently and effectively accomplish control densification and mapping with the same set of photography? If so, such a combination has definite appeal because of the reduced costs. In particular, such a system would be a good candidate for multipurpose cadastre applications where a densified control network and large-scale base maps are two of the key components (National Research Council, 1980).

In order to address the question concerning combined control densification and mapping described above, it is necessary to define a few parameters. Specifically, what does large scale mean, how dense should the control densification be, and how accurate?

First, for the purposes of this discussion, let us assume that most large-scale mapping needs can be met by scales of 1:4,800, 1:2,400, and 1:1,200. In fact, these are scales frequently used by local governments for mapping rural, urban, and highly urbanized areas, respectively, for tax assessments. This mapping is routinely accomplished by generating orthophoto base maps from aerial photography flown at a scale five times smaller than that of the map produced. We will investigate the possibility of producing maps at one of these scales from photography flown for photogeodesy.

Second, the level of control densification desired will vary depending on the specific application and need. However, for the purposes of this investigation, let us assume that geodetic positions are to be established at one-mile intervals (i.e., on section corners in the Public Land Survey System). Third, the level of accuracy for the densified points also varies with the specific situation, but for our purpose here we will assume that a third-order, class I geodetic position (1 part in 10,000) will suffice.

PROBLEM SOLUTION

In summary, the specific problem that has been defined is the achievement of control densification at one-mile intervals to third-order, class I standards (1 part in 10,000) and the production of a map at a scale of 1:4,800, which meets the NMAS, both from the same set of photography. This problem will be addressed in two parts and the results combined to show the collective solution.

CONTROL DENSIFICATION

First, control densification by photogeodesy has been demonstrated by NOS and results have been reported by Slama (1978), Lucas (1981 and 1984), Perry (1984), Fritz (1985), and others. The primary focus of this photogeodesy application was to attain the highest possible accuracy and precision. The effort was successful in consistently establishing positions accurate to 5 cm over a one-mile spacing. However, in order to achieve this high accuracy, a rigorous methodology is necessary. Also, as a side effect of using the geodetic lens cone and optimization of film processing for the geodetic target wavelength, the resolution of the nontargeted features is not sufficient to support large-scale mapping. A summary of the procedures/specifications used for precise photogeodesy is shown in Appendix I. Note: the bulk of this information was extracted from Fritz (1985). Prior experience with photogeodesy has led to the development of standards and specifications for control extension by photogrammetric methods (Federal Geodetic Control Committee, 1984). Obviously, establishing third-order, class I horizontal control by photogeodesy (16 cm or 0.53 ft over a one-mile spacing) requires less vigorous procedures. Various criteria have been set forth by the Federal Geodetic Control Committee (FGCC) in the 1984 publication, *Standards and Specifications for Geodetic Control Networks*. The portion of this publication which deals with photogeodesy is section "3.6 Photogrammetry." Using it as a guide, the procedures for photogeodesy listed in Appendix I can be relaxed to achieve third-order, class I results. The recommended procedures/specifications are shown in Appendix II, where the specific items which have been relaxed are marked with an asterisk (*). One of the most significant changes is that these procedures can be accomplished using a typical good quality metric camera (Wild RC10 or Zeiss RMK-A) with eight fiducial

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 53, No. 6, June 1987, pp. 609–612.

0099-1112/87/5306–609$02.25/0

marks (and standard mapping film), instead of a specially focused lens cone with 1-cm reseau.

A close comparison with the FGCC publication will reveal that some of the procedures recommended here for third-order, class I photogeodesy exceed the minimum guidelines specified by the FGCC. This has been done intentionally to provide a safety factor. As more experience with these procedures is gained, more relaxation should be possible.

To my knowledge, the exact procedure described above has not been used in a control densification project. However, it is fully feasible, it should work, and it should produce the desired results.

J. McKenna and M. Snyder of Air Survey and Design, Inc., Herndon, Virginia (unpublished data, 1986) have experimented with *ad hoc* procedures similar to, but not as rigorous as, those described in Appendix II. They obtained results in which the largest positioning error was 25 cm (10 in) and the majority of the errors were 15 cm (6 in) or less. (Also see J. McKenna, "County-Wide Control Network Using Photogeodesy and Global Positioning Systems — A Realistic Approach," unpublished paper, 1986).

Therefore, in summary, a specific workable procedure has been identified to produce control densification at one-mile spacing to 1 part in 10,000.

Mapping

The second part of the problem is the production of usable maps which meet the NMAS from the same photography flown for the photogeodesy. The photography described above is flown at a scale of 1:24,000.

The approach suggested for mapping is to produce orthophoto base maps by performing differential rectification of the photography so as to remove the distortions due to tilt and relief displacement. These maps differ from conventional line maps in that they show a photo image background. This photo background allows the user to interpret photo images for their own specific applications. For example, tax assessors can easily identify apparent property lines from fence lines, rows of trees or shrubs, alleyways, etc. Soil types and drainage patterns are also often evident in the photos.

The procedure recommended for map production is to produce a diapositive and employ an orthophoto scanning instrument such as the Topocart to produce orthophoto map sheets. This procedure involves compiling the maps at a scale that is five times larger than the scale of the contact aerial photography. This approach is in accordance with industry standards for orthophoto mapping. State plane coordinate ticks can be superimposed on the orthophoto map to enhance the map's overall usefulness.

A listing of "Recommended Procedures/Specifications for Orthophoto Base Mapping Done in Conjunction with Photogeodesy" is presented in Appendix III. This information was taken largely from an actual contract specification prepared and used by Spartanburg County, South Carolina (Spartanburg County unpublished specification, 1985). Because this procedure is an accepted, routine industry standard used by reputable contractors, further discussion here is not required.

Thus, these two independent procedures for control densification and mapping can be combined to yield tremendously useful products from the same aerial photography. (In reality, the control densification must be done first because the resulting control will be used to scale the map.)

RECOMMENDATIONS

In order to demonstrate convincingly that third-order, class I control densification and mapping can be done with commercially available equipment using the same set of photography, it is recommended that an appropriate test project be performed.

Assuming the successful completion of the test project, a pilot project should be arranged to demonstrate the technique in an operational situation. Such a project could logically be a multipurpose cadastre pilot project designed for a specific county in need of both control densification and mapping to attain its objectives. Although this project could obviously be performed by NOS, it may well be more significant for the surveying and mapping community if it were accomplished by a commercial contractor following NOS standards and specifications and under NOS guidance. This would demonstrate to potential users that the procedure is not a specialized technique which only NOS can accomplish.

REFERENCES

Brown, Duane C., 1977. Densification of urban geodetic nets, *Photogrammetric Engineering and Remote Sensing*, Vol. 43, pp. 447–467.

Federal Geodetic Control Committee, 1984. *Standards and Specifications for Geodetic Control Networks*, National Geodetic Information Center, NOAA, Rockville, Md., 29 p.

Fritz, Lawrence W., 1985. Photogeodesy, *Vermessung Photogrammetrie Kulturtechnik* (commemorative issue honoring Prof. Dr. H. H. Schmid, Technical University, Zurich, Switzerland), pp. 306–309.

Lucas, James R., 1981. *Results of photogrammetric control densification in Ada County, Idaho*, NOAA Technical Report NOS91 NGS 21, 77 p.

———, 1984. Photogrammetric densification of control in Ada County, Idaho: Data processing and results, *Photogrammetric Engineering and Remote Sensing*, Vol. 50, No. 5, pp. 569–575.

National Research Council, 1980. *Need for a Multipurpose Cadastre*, National Academy Press, Washington, D.C., 1980, 122 p.

Perry, Leslie H., 1984. Photogrammetric summary of the Ada County project, *Photogrammetric Engineering and Remote Sensing*, Vol. 50, No. 5, pp. 563–567.

Slama, Chester C., 1978. High precision analytical photogrammetry using a special reseau geodetic lens cone, *Proceedings of the International Society of Photogrammetry Commission III International Symposium*, International Society for Photogrammetry, July 31-August 5, 1978. Moscow, U.S.S.R.

(Received 23 December 1986; accepted 11 February 1987; revised 6 March 1987)

APPENDIX I
PROCEDURES/SPECIFICATIONS USED FOR PRECISE PHOTOGEODESY

1. Two thirds forward and side overlap of photography.
2. All pass points and control points targeted.
3. Each control and pass point appears on at least nine photos.
4. Use flight attitude such that exactly 16 ground targets, spaced at one-mile intervals, are imaged on a perfectly centered photograph.
5. Ground Control – Horizontal control to support precise photogeodesy shall be positioned to first-order, class I accuracy and spaced five to six photo air bases around the perimeter of the project area. One additional horizontal and one vertical control station shall be located near the center of the project. This center area control should be located no more than seven air bases from the perimeter control. The vertical control must meet third-order standards.
6. Camera – wide angle
   - 2 cm or closer spaced reseau calibrated to < 1 micrometre
   - full stellar calibration of lens parameters to < 1 micrometre
   - plane of best focus optimized for color (wavelength) of ground targets
7. Film – Black and white, expose one or two stops under exposure to accentuate the high energy (fluorescent) targets.
   - Original negatives used for measurements.
   - Color film used to fly secondary set of photos at

about three times larger scale than black and white to provide positive office identification of targets.

8. Targets – Precisely circular with 1.0 to 1.2 cm hole cut in center; fluorescent; placed on a black matte background; sized to produce 40 to 80 micrometre images.
9. Metric comparator – Fully calibrated to provide accuracy < 1 micrometre; environmentally controlled at film plane to 1 degree F and 5 percent relative humidity; automatic prepositioning control; digital input and output.
10. Digitizer – Backlighted; digital output; < 0.1 mm resolution.
11. Original film (negative) is indexed, cut into single frames, and bagged in clear plastic ziplock envelopes.
12. Approximate nadir of each photo and all target locations are marked on USGS quads. These points are digitized and transformed to ground coordinates.
13. A few selected targets and reseau points are digitized and a single-photo resection is computed for each photo. Approximate photo coordinates for all targets and reseau points are then computed using the results of the resection solution. These approximate positions are used to automatically guide the comparator to the next point to be positioned.
14. Photograph measurement is performed on the National Ocean Service Laser Mann Automatic Stellar Comparator (LMASC) using input paper tapes containing all positions generated by the single photo resection program. LMASC measurements are accurate to 0.7 micrometre.
15. Each ground target and its nearest six reseau points are measured. Each target and reseau point is measured five times. The digital output of the LMASC is processed through edit, coordinate refinement, and strip/block adjustment programs.
16. Edit – Obvious blunders and data cleanup or rearrangement is accomplished
17. Coordinate refinement – Computes mean of multiple pointings; applies nonlinear comparator calibration correction; performs a general affine linear transformation of each target point to remove film distortion and linear comparator errors and then transforms all target points into the calibrated coordinate system of the camera; prints residuals and statistics; deletes all reseau points; applies lens distortion corrections from the stellar calibration, then computes a single-photo resection using the digitized quad positions.
18. Strip-block adjustment – The refined photo coordinates, updated camera station parameters, and target coordinates are input to the adjustment. Each strip of photography is processed separately to detect blunders and weaknesses before being combined to form the full block. The solution is performed by eliminating the ground points (targets), solving for the camera stations and then for the ground points. An alternate adjustment program proceeds by elimination of the camera stations and solving for the ground points. This approach allows for easy determination of the distance, azimuth, and elevation difference with corresponding variance and covariance for intervisible ground points.

APPENDIX II
RECOMMENDED PROCEDURES/SPECIFICATIONS FOR THIRD-ORDER, CLASS I PHOTOGEODESY

1.* Two-thirds forward and one-third side overlap of photography.
2. All pass points and control points targeted.
3.* Each control and pass points appears on at least four photos.
4. Use flight altitude such that exactly 16 ground targets, spaced at one-mile intervals, are imaged on a perfectly centered photograph.
5.* Ground Control – Horizontal control to support third-order, class I photogeodesy shall be positioned to second-order, class I accuracy and spaced five to six photo air bases around the perimeter of the project area. One additional horizontal and one vertical control station shall be located near the center of the project area. This center area control should be located no more than seven air bases from the perimeter control. The vertical control must meet third-order standards.
6. Camera – Wide angle
   * – Eight fiducial marks required.
   * – Calibration of lens parameters to 3 micrometres.
   * – Plane of best focus set for best possible images for both ground features and targets.
7. Film – Black and white, expose to accentuate ground.
   * features are targets.
   – Color film used to fly secondary set of photos about three times larger scale than black and white to provide positive office identification of targets.
8. Targets – Circular with 1.0–1.2 cm hole precisely cut in center; fluorescent; placed on a black matte background; sized to produce 40 to 80 micrometre images.
9. Metric comparator – Fully calibrated to provide
   * 2 to 3 micrometre accuracy (1 micrometre least count); environmentally controlled at film plane to 3 degrees F and 10 percent relative humidity;
   * digital input and output optional.
10. Digitizer – backlighted; digital output; < 0.1 mm resolution.
11. Film (negative) is indexed, cut into single frames, and bagged in clear plastic ziplock envelopes.
12. Approximate nadir of each photo and all target locations are marked on USGS quads. These points are digitized and transformed to ground coordinates.
13.* A few selected targets and fiducial points are digitized and a single-photo resection is computed for each photo. Approximate photo coordinates for all targets and fiducial points are then computed using the results of the resection solution. These approximate positions can be used to automatically guide the comparator to the next point to be positioned.
14.* Photograph measurement is performed on a high quality comparator or analytical stereoplotter capable of making measurements good to 2 to 3 micrometres. Input tapes containing all positions generated by the single photo resection program could be used to drive the comparator to the approximate location.
15.* Each ground target and the fiducial marks are measured. Each target and fiducial mark is measured three times. The digital output of the comparator or analytical stereoplotter is processed through edit, coordinate refinement, and strip/block adjustment programs.
16. Edit – Obvious blunders and data cleanup or rearrangement is accomplished.
17. Coordinate refinement – Computes mean of multiple
   * pointings; applies comparator calibration correction; performs a general affine linear transformation of each target point to remove
   * film distortion and then transforms all target points into the calibrated coordinate system of the camera; prints residuals and
   * statistics; deletes all fiducial marks; and
   * applies lens distortion and corrections from the camera calibration.
18. Strip/block adjustment – The refined photo coordinates,

---

* Denotes items that are different (less stringent) than the procedure for Precise Photogeodesy. Items 10, 11, 12, and 13 are optional, but recommended (i.e., other procedures which accomplish the same purpose without any loss of precision could also be used).

updated camera station parameters and target coordinates are input to the adjustment. Each strip of photography is processed separately to detect blunders or weaknesses before being combined to form the full block. The solution is performed by eliminating the ground points (targets), solving for the camera stations and then for the ground points. An alternate adjustment program proceeds by elimination of the camera stations and solving for the ground points. This approach allows for easy determination of the distance, azimuth, and elevation difference with corresponding variance and covariance for intervisible ground points.

APPENDIX III
RECOMMENDED PROCEDURES/SPECIFICATIONS FOR ORTHOPHOTO BASE MAPPING DONE IN CONJUNCTION WITH PHOTOGEODESY

1. Conditions during photography – Deciduous trees barren, sun angle not less than 30 degrees, ground not obscured by snow, haze, fog, or dust, streams within their normal banks, photographic targets plainly visible.
2. Scale of aerial photography negatives – For a map scale of 1:4,800, use negative scale of 1:24,000; scale deviations of greater than 5 percent are not permitted.
3. Flight coverage – Principal points of the first two and the last two exposures of each flight strip shall fall outside the boundaries of the area to be mapped, and all side boundaries shall be covered by minimum of 25 percent of the photo image format.
4. Endlap and Sidelap – Photographs used for orthophoto mapping shall have 66 percent endlap and 33 percent sidelap.
5. Crab and Tilt – The crab shall not exceed 3 degrees; tilt shall not exceed 3 degrees on any given exposure, and should average 1 degree for the entire project.
6. Aerial camera – A precision aerial mapping camera (Zeiss RMK-A, Wild RC10, or equivalent) equipped with a low distortion, high resolution lens is required. Camera must produce a 9 by 9-inch negative with eight fiducial marks in each negative. Camera must be calibrated within the tolerances prescribed by the FGCC Standards for third order, class I photogeodesy.
7. Aerial film – Use black-and-white film which is a fine grain, high speed photographic emulsion on a dimensionally stable base. The container for each roll of film shall not exceed 6 inches in diameter and shall not contain more than 250 feet of film.
8. Film processing – Film shall be exposed and processed with a target density range of 1.0 +/− 0.2, as measured in the neat image areas of each roll of film. Minimum density, as measured with a densitometer with a scale range of 0 to 3.0, should not be less than 0.3, and the maximum density not greater than 1.5. All fiducial mark images shall be clear and sharp. Images on the aerial negatives shall be clear and sharp in detail and free from light streaks, static marks, scratches, and other blemishes. Special care shall be taken during film development to avoid stretching or distortion of the film.
9. Ground control – Horizontal control to support orthophoto mapping and third-order, class I photogeodesy shall be positioned to second-order, class I accuracy and spaced at five to six photo air bases around the perimeter of the project area. One additional horizontal and vertical control station shall be located near the center of the project area (the vertical control must meet third order standards). If contours are desired, additional vertical control will also be required.
10. Diapositives – All diapositives will be reprinted from original aerial photography negatives. Glass diapositives will conform to Kodak Ultra Flat Glass Specifications for Aerographic positive plates or equal. If film positives are used, they will be printed on cut sheets of Kodak Aerographic Duplicating (Estar Thick Base) Film No. 4427, or equal, and on a printer having a flat platen.
11. Analytical aerial triangulation and high-to-low aerial triangulation will not be required to establish control for photogrammetric compilation. The control established at one-mile intervals by photogeodesy can be used to control the mapping compilation.
12. Preparation of orthophoto base maps–
    a. The outside edge dimensions of all base map sheets shall be 30 inches high by 40 inches long. The neat image area shall be 25 inches by 25 inches.
    b. All base maps will be produced in strict accordance with accepted stereophotogrammetric procedures for the map scale. The maps shall be compiled for each area at a scale equal to or larger than the scale required. Map compilation scales for the areas mapped will be limited to an approximate five times enlargement over the scale of the aerial photography for each area. Only precision stereoplotting instruments shall be used in compilation work.
    c. Coordinate grid ticks – The plotted position of each plane coordinate grid tick shall not vary by more than 0.01 inch from true grid value on each manuscript.
    d. Horizontal control – Horizontal control points shall be plotted within the coordinate grid in which they lie to an accuracy of 0.01 inch of their true position as expressed by the plane coordinates for the control points.
    e. Planimetric features – Ninety percent of all planimetric features shall be plotted so that their positions on the finished map will be accurate to within 1/40th of an inch (0.025 inches) of their true coordinate positions; and none of the features shall be displaced on the finished map by more than 1/20th of an inch (0.05 inch) from its true coordinate position.
    f. Grid lines and values – State plane coordinate grid intersections are to be plotted at 5-inch intervals. Grid line intersections (1/2 inch in length) shall be shown throughout the next image area. Grid values shall be printed in the margin along the image area border at the western (left) and northern (top) ends of the map sheet.
13. Final orthophoto base maps shall be prepared by differential rectification. The orthophoto image shall be extended to at least 2,000 feet beyond the project boundary lines. When adjacent maps are aligned by grid ticks, imagery will not be displaced by more than 1/40th of an inch.
14. Compilation – Each stereo model to be scanned shall be free of residual parallax and shall be leveled and scaled to plotted control to an accuracy consistent with the map accuracy requirements described above. Each stereo model shall be scanned with a slit width compatible with the terrain and at a speed which will achieve a good photo image and the required accuracy.
15. The map sheets will be prepared on a high quality, stable polyester material suitable for photographic reproduction, such as DuPont cronaflex or equal, with a minimum thickness of 0.004 inch and having a matte surface on both sides.