Photogrammetry in Practice

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ABC's of Problem Solving in Analytical Bridging*

Five areas in which errors might occur are identified and corrective measures are described.

Abstract: *What course of action should one follow when using full analytical bridging if something should happen to go wrong? Analytical bridging may be economical and convenient, but what good is it if one is unable to get the process to work? Steps to follow in isolating the cause and effect of errors, along with recommended corrective measures to recover the bridging project, are outlined. These actions have evolved from over nine years of use in highway mapping.*

Introduction

Analytical bridging for large scale mapping has many benefits to consider, such as being able to map large, densely populated areas; providing control with a minimum of encroachment upon private lands; being able to map hard to reach areas such as bodies of water; having less hassle with dense traffic; leaving less damage to private property; providing a map with less manpower; providing a more accurate product; etc. These are some of the major benefits, but there are also drawbacks. For instance, one must fly most of the photography in early spring when the winds and thermal drafts are at their worst, surveying must be accurate, one must contend with property owners with guns (not unique to bridging), there are too few flying days, etc. These are the external parameters to the bridging process. Now, let's take a look at the interior operations and the day-to-day problems.

Errors-Mistakes-Blunders

Whatever you call them, errors still occur. One must accept this fact. With the many manual operations performed by many different people, mistakes will occur from time to time. The fact that a mistake occurs is not the major problem. When one does happen, how do you detect it and what are you going to do about it. Analytical bridging will not prevent errors from happening nor will it find them all. I only attempt to point out the more serious variety that we have encountered over nine years of exposure to bridging.

Analytical bridging is something like a hand. Each has five fingers, all joined together by a common bond. The five fingers of analytics are

- Field Control,
- Photo Acquisition,
- Marking and Measuring,
- Computer Programs, and
- Stereo-compilers.

The common bond is communication. Even though each finger is capable of operating by itself, the total effect is much greater when they all work together. Open communication channels through all phases of bridging will do wonders for the overall effect. Asking other people to help solve a problem will keep the lines open and operating much longer than blaming the other guy for mak-

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ing a mistake, especially if he finds out it was your mistake all along. This cooperative effort is needed to keep a large bridging program going. The more each group knows about the needs and operation of the other group the better each group can attune his efforts to the end product.

The five fingers are treated individually because the problems in each are not common to the other phases of the process.

FIELD CONTROL

Field Control is probably the most critical input element of the analytical bridging process and the element with which we have the most trouble. One major contributing factor is that surveying is performed by the office that requests the mapping. We provide a minimum of supervision and consultation to most jobs. We do provide horizontal control for some jobs when the requesting office lacks the trained personnel or proper equipment. The stipulation, that the office making the request for mapping also provides the field control, is often a problem. The completion of their request is encumbered by their own lack of capacity to provide ground control. Users of our services have sometimes given us impossible deadlines when they cannot provide their end of the bargain. The quality of provided field control is often weak. When the bridging solution has detected an error and we have not been able to resolve the problem in the office, a return to the field has found the surveying information to be in error a majority of the time.

The computer programs we use indicate how well the analytical results fit the control points. Careful manual scanning of the program residuals will depict the most likely point in violation, if one exists. This point can be removed from the control pattern and the triangulation can be resubmitted for computer analysis and another look at residuals. This procedure will work for one or two points in conflict. More than two points are very difficult to isolate and remove from control, and more drastic measures must be taken. All office procedures must be checked before returning to the field. These include

A. Point marking, for false stereo and location
B. Measuring, reread plates
C. Identification
   a. Make sure field and office identification are for the same physical point
   b. Inadvertantly changing a point number from photo to photo
   c. Point marked on one photo only
D. Transposition of numbers
E. Two points with the same identification number
F. Wrong lens data
G. Field and office personnel review all control points for physical location. Recheck all information.

The last recourse is to return to the field to check the original values.

The ideal control pattern is equilateral triangles on each end of the strip with two points in each end model and the third point in the second model. When using the 3-Photo Analytical Analysis and the Strip Adjustment computer programs, a six model bridge should have the end control points supplemented with a control point near the center of the strip. Seven to nine models should have two wing points near the middle of the strip. Ten to 14 should have a diamond pattern near the center of the strip. Strips longer than 14 models can be run by the 3-Photo program but vertical will tend to flatten out in Strip Analysis, thereby giving erroneous results. We have run strips as long as 43 photos. We did this to locate horizontal control problems, then we dropped back to 10 to 14 photos in a strip for our useable results. The above idealistic pattern is not often so easy to achieve. We have had satisfactory results using almost any geometrically well-balanced pattern, and some very sad results with unbalanced patterns. Our present practice is to add extra field points to the control network, thus ensuring sufficient control in case we were to lose one or two points in bridging. We have bridged conventionally controlled jobs, for various reasons. We have had apparent errors in field control that could not be resolved on the plotters. We have been able to isolate the problems by bridging and then have completed the project without more field data. We have also salvaged conventionally controlled jobs where the targets have either been destroyed or have failed to show on the photography for other reasons. This has a twofold benefit: First, we don't need to return to the site to replace the targets; and second, we just do not have that many flying days available to refly the job.

We have used targeted or pre-control and post-control. Each has its advantages and disadvantages. Pre-control usually presents a sharp image on the photo, thereby causing little problem with misidentification. We do have trouble maintaining targets from the time they are put in place until the photography is obtained. This time interval can be up to a month or more as we wait for weather conditions to clear. Post-control is probably the favorite method of the field personnel because they can plan the traverse routes, pick the control points, do the reconnaissance, etc., all with a photo print in hand. When we are doing block work, post control is better because the most expedient and economical routes can be planned. Post-control also permits more flexability to the flight crew because they can get the photography when they are in the area regardless of targets or no targets. The disadvantage to post-control is the possibility of misidentification between "Marking and Measuring" and Field Control. We keep this misidentification low by going over the control points with "Marking and Measuring" and the field personnel before going to the job site.

Telephone communication between the field and office crews clarifies most point identification problems when an alternate is needed by the field. We have found that this system works very well.

PHOTO ACQUISITION

Photo Acquisition is a critical phase of the operation but probably has more latitude than any other phase. The problems that can arise here are poor exposure, missed alignments and flight heights, excessive tip, tilt, or swing (angular orientation parameters), image motion, etc. Poor exposures can be somewhat compensated for when the film is developed by changing the development time. A missed alignment or a wrong flight height, which makes the film unuseable, could be a communication problem between flight planning and the flight crew. Excessive angular orientation and image motion are problems when acquiring low elevation photography. Angular orientation up to a point is acceptable and can be handled by the stereoplotters, but image motion cannot be handled. The "as slow as possible" flying can introduce circular image motion due to the instability of the camera platform. This motion is hard to detect on visual inspection of the film and is much more difficult to handle in the plotters than is lineal image motion due to flying too fast.

The only information on acceptable image motion, that I have found, is in the Wild RC-10 instruction manual. The manual indicates that Kodak Double-X film has an allowable image motion of 25 micrometres and Tri-X has an allowable image motion of 35 micrometres. The forward ground speed of the airplane should be as close to these values as possible. The flight crew can match their speed to the job site conditions and possibly fly at a ground speed considerably faster than "as slow as possible." A faster speed should give a more stable camera platform. It is possible that, by increasing speed to the detection level of image motion, the other motions drop to well within the prescribed limits. This could result in sharper overall photos.

Table 1 is derived by relating image motion to ground speed. Table 1 holds true for any focal length. It is self-defeating to fly slower than the table indicates. The slower the plane flies the more it wallows and the more chance one has of getting circular image motion. It is possible to work with some lineal image motion, but circular image motion is really wild. Therefore, open up the *f*-stop and decrease the shutter time. The image sharpness loss due to a wide-open lens will only affect the outside edge of the photo, which in any case is not used in the stereocompilers. It is far better to have a good partial photo than one that is bad all over.

MARKING AND MEASURING

Marking and measuring has more built-in checks and balances than the other components of analytical bridging, but "fear not" errors can still creep into this area. The operators have the responsibility to mark and measure each location of a point throughout the strip. The plate density can either assist or hinder the marking accuracy. Light or thin plates used in projection plotters are more difficult to mark accurately than the denser plates used on optical train plotters. The image becomes quite soft on the lower density plates and the "on the ground" positioning of the point becomes questionable. The darker plates give a nice, crisp image.

False stereo is another problem that the operator must try to avoid. This can happen when passing points from strip to strip, the lighting conditions vary, and when there is a lack of physical reference to positively identify the point (e.g., an open field).

Halation is a problem to content with, but an experienced operator is aware of the condition and will compensate for it. This is one of the problems with pre-control targets. They do halate and it is sometimes difficult for the operator to drill the point in its true position.

The description of a point can vary between the field and marking crew, causing misinterpretation of the point location. What

TABLE 1. AIRCRAFT GROUND SPEED (mph) AS A FUNCTION OF CAMERA SHUTTER SPEED AND PHOTOGRAPH SCALE FOR ALLOWABLE IMAGE MOTIONS OF 25 AND 35 MICROMETERS

Camera Shutter Speed, 1/N	Contact Scale 1:3000		1:6000		1:12,000	
N	25M μm	35M μm	25M μm	35 M μm	25M μm	35M μm
100	17	23	34	47	67	93
200	34	47	67	93	133	187
300	50	70	100	140	200	
400	67	93	133	187		
500	83	117	167	233		
600	100	140	200			
700	117	163				
800	133	187				
900	150	210				
1000	167					

seems to be evident in the field is confusion in the office (for example, east side of bridge, north side of pole, or the right edge of pavement). The identification of the point in numerical form can be changed, altered, transposed, etc., until it indicates an entirely new location.

There are smaller errors that should be considered and addressed. Visual acuity and eye fatigue will vary from operator to operator. Some people will experience a new type of eye strain and problems may occur of which they are not aware. Mechanical adjustments must be made to compensate for plate thickness or film diapositives. This is done to place the reticule of the instrument on the surface of the film. The same marked size drills will produce different sized holes at the working level of magnification. Select drills that will produce matched hole sizes.

Errors that can occur in the measuring consist of the inherent ones in the device itself. These are removed by calibration. There are other minor adjustments made for individual eye differences and comfort. Care should be taken to assure the reliability of the measured data. The operator should return to the point of beginning after all points on the plate have been read. He should read the same values on the reread as he did on the initial reading. This should be done on all instruments that make only one reading per point per plate. There is always a possibility of plate slippage. If the instrument is digitized one can always lose reference due to plate slippage or a power surge. The reread is an operator check on reliability of data. Other type of reading errors that are more operator oriented are

- leaving out a point,
- renaming a point, and
- improper positioning of the reticle.

The marking and measuring errors I have just discussed are for the large part detectable or compensated for by computer programs. Three-Photo Analysis will give a residual which, more or less, is the operator repeatability rating. An error in excess of a preset value (25 micrometers) will stop the program.

COMPUTER PROGRAMS

Computer programs, after they have been used for a few years, have virtually all errors removed. The probability of an error being generated by the programs themselves is very remote. They are not, however, infallible and will accept input errors as readily as good data. Therefore, there should be sufficient data in the input that the loss of one or two points will not impede the solution.

For a unique solution to the adjustment polynomials, the minimum number of control points necessary are as follows:

Degree of Adjustment	Minimum Number of Control Points	
	Horizontal	Vertical
1st	2H	4V
2nd	3H	5V
3rd	4H	7V

We normally use the second degree adjustment but, for the first run through, the programs automatically run all three degrees of adjustment and then select the best fit combination for the output values. This aids in detecting errors. On one project a second degree equation was used, but when the job was plotted at a scale of 1:600, errors of 2 to 5 feet were found in the Y direction at the edges of the model sheet. We reran the job with third degree adjustment and the points moved out to their proper positions. This job had vertical differences of one-tenth the flight height from one side of the strip to the other, with most of the difference in a bluff near the center line of photography.

The residuals produced by Strip Adjustment are a measure of how well the analytics fit the field values of control points. A rule of thumb of acceptable values of these residuals is 1/1000 of the flight height for horizontal and 1/1500 of the flight height for vertical. Therefore, residuals larger than the above values would indicate a need for investigative actions. The most likely data error is the control point with the largest residual. Check the office procedures for errors and if none are detected, remove the questioned point from the control deck and rerun the program. We also check one major facet of the program. The residuals (A) are expressed in feet and show how the formula fits the control. This formula is used to compute the coordinate values of all points in the analytical bridge. When a control point is computed, we output the differences (B) between computed and input values. If there is a difference between (A) and (B), the results should not be used. Add more control or lower the degree of the equation.

The Strip Adjustment program will not produce reliable results for pass points that lie outside of the control points on the ends of the strip. This phenomenon is not as evident across the strip. It is good practice to have lengthwise control outside the area to be mapped and crosswise control near the mapping edge.

Our programs will work with 9, 12, 15, or 18 pass points per photo. Point names or numbers can be of any numeric value. Pass points must appear on three consecutive photos. All other points must occur on two consecutive photos in order to have final computed values.

STEREO COMPILERS

Stereo-compilers are the final test of analytical analysis. Using the output of the computer programs, the models can be set and cleared in 5 to 15 minutes after the plates are installed in the instruments. The models are almost always cleared of y-parallax because most of the differences have been adjusted by the programs. The operator may not be able to work a model even though it will set, clear, and level. This may be due to image motion.

We have had large angular orientation differences in adjacent photographs (7.4 grads of swing, 3.9 grads of tip, and 3.4 grads of tilt). These values did not occur on the same photos but they did occur on the same job. The optical train plotters will handle differences of this size. These values do not indicate image motion but, when the aircraft is being tossed about as shown by these values, the chances are fairly good that the camera shutter will be open during a gyration of the aircraft, thereby causing image motion.

We have had models with one side of a pond higher than the other side; cause, field error not detected until now; result, start over. We have had models which we could set, clear, and level but we could not work them; probable cause, circular image motion; result, obtain new photography. We have worked models where the water appears to flow uphill; possible cause, heavy tip; result, slow, hard work for the operator.

The "as slow as possible" flying very definitely increases the tip, tilt, and swing in the model set-up. How much we can handle and still produce a good mapping product is not known.

Poor ground control, thin diapositives, image motion, misused computer programs, etc., all go into the finished product. How much any one or all of these factors affect the final product may be hard to measure, but it surely affects the ease and comfort of the operators.

We do not check each mapping job, but we do spot-check from time to time with good results.

Due to running so many analytical jobs, we have altered our method of selecting points for conventional control. The open communication channels between field and office has definitely affected our conventional method and final product.

Conclusion

I have discussed various types of errors one can encounter when using analytical bridging, and some alternatives of action one can employ to recover the project without all efforts, up to the error discovery, being a total loss. The loss of a control point from the process does not indicate the field position is in error. It just points out that something has gone awry somewhere. Take time to assure yourself that the error, as such, is not recoverable in the office, then drop it and continue on. The time taken to return to the field to isolate these breaks defeats the time saving benefit of the process. This does not mean that field work must be performed at second order to protect oneself when third order is adequate for the largest scale maps we make.

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