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Digitizing and Automated Output Mapping Errors

Tests were designed and carried out for determining how well digitizing and subsequent output plotting could be performed.

Abstract: *Computer assisted cartography and mapping have become a reality. However, the errors concerned with these operations are still somewhat uncertain. Under the conditions found at the Army Survey Regiment, Bendigo, Australia, the errors associated with the digitizing of discrete points and the automated output of these points onto contact film were found to be 3.3 m and 1.9 m at ground scale (±0.082 mm and ±0.037 mm at table scale). The frequency of capturing digits and the expected errors when digitizing nondiscrete points (i.e., when the cursor is continuously in motion) are also discussed.*

Introduction

The purpose of this paper is to report the results of an examination into the size of digitizing and automated output errors.

The organization examined was the Army Survey Regiment, Bendigo, Australia, which utilizes computer assisted mapping in two ways. First, upon conclusion of the aerotriangulation/block adjustment phase (Schut's 3rd order polynomial), a compilation team sets up the models on Wild B-8's which are equipped with tri-axis locators and encoders. All required information is converted to digits and stored, awaiting output at the appropriate scale.

Second, the computer controlling the output subsystem is instructed to output the stored information by means of its optical exposure head onto contact film.

This paper is concerned with how well these two operations are performed.

Test Design

Precise relative positions were determined for a number of test points previously selected on glass diapositives. The diapositives were then placed on Wild B-8's, relative orientation was achieved, and the test points were digitized by four different operators, all using normal mapping procedures. The test points were then exposed onto film by the computer-assisted output subsystem. In both cases, the relative positions, after the computer-assisted operation, were compared to "truth," that is, to their relative locations prior to the operation.

Initially it was important to determine accurately the relative positions of all test points. This was accomplished in the following way.

Two sets (six models each) of glass diapositives at the normal mapping scale of 1:80,000 were produced on the organization's Wild U4A projection printer utilizing standard production methods. After some collaboration, two operators (named A and B) independently point-marked (Wild Pug IV) approximately 60 widely dispersed points on each set of diapositives (numbered 1 and 2). The terrain was sparsely covered and gently rolling with a difference in elevation of approximately 100 metres. Using a Zeiss (Jena) Stecometer, each operator measured his diapositives and those of his associate. This resulted in four distinct sets of fully measured diapositives (A-1, B-1, A-2, and B-2).

With the aerotriangulated points from the original block (1:80,000) serving as control, four separate aerotriangulations covering the six-model test area were conducted. One would expect the relative accuracy of the 60 aerotriangulated test points over this small area to be excellent. However, so as not to unjustly penalize the system later in the evaluation of the accumulated error, Gauthier's (1970) concept of determining the internal accu-

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racy of the aerotriangulation was employed. In particular, the planimetric errors of tie points were computed for each of the four separate local aerotriangulations. These errors (Table 1, Column 2) were statistically removed before the digitizing error was computed. The aerotriangulated positions of the 60 test points on each of the four sets of data (totaling about 240 test points) served as "truth" against which the digitized values were compared.

Digitizing Error

Four individual Wild B-8 operators each oriented, at a scale of 1:40,000, a set of six models containing what was to become a 1:50,000 test map. They then carefully digitized, as discrete points, each of the 60 previously point-marked and aerotriangulated test points. The digitized values were then compared directly to the aerotriangulated values. A root-mean-square error (RMSE) was computed for each set of test points where RMSE $= [\Sigma V^2/(n - 1)]^{1/2}$, $V^2 = (DX^2 + DY^2)$ and n is the sample size. DX and DY are the X and Y differences between "truth" (aerotriangulated values) and the digitized values.

Table 1 depicts the error contribution of the digitizing operation for each set of test models. With the internal inaccuracy statistically removed, the average digitizing error becomes 3.3 m on the ground (±0.082 mm on the Wild B-8's).

An unexpected but fortuitous bonus resulted from 48 points which were digitized more than once. This resulted either because the operator forgot that he had previously digitized the point or, more likely, because it appeared on more than one model. Theoretically, there should be no difference in the doubly digitized value. In practice, of course, one would expect a difference.

It became apparent that the average vector difference between the two independently digitized points should closely approximate the previously computed digitizing RMSE.

In this case because a direct comparison was being made between two values, neither of which could be considered as truth, the average of the 48 vector differences was computed.

The absolute value of this difference for the 48 doubly digitized points was 3.2 m. This coincides extremely well and adds credence to the digitizing error of 3.3 m. It seems reasonable that, if the repeatability between two points was a little over 3 metres, then surely you would not expect the comparison between the digitized coordinate and "truth" to be much different. This was found to be the case.

Continuous versus Discrete Digitizing

A number of points (road junctions, fence corners, etc.) were digitized as the intersection of two lines (i.e., continuously) as well as a discrete point. That is, starting about 2 cm on one side of a road junction the operator would move the measuring mark through the intersection and extend about 2 cm beyond. By doing the second road in the same manner it became possible, through a comparison of the X and Y output, to locate the value of the actual intersection. This allowed for a comparison of points digitized both continuously and discretely (see Figure 1).

Thirty-two points on the four test sheets were obvious intersections of two lines (roads, fences, streams, etc.). The computer print-outs giving the X and Y values were examined and the intersection of these two lines determined. This value was compared to "truth" (aerotriangulated values). The RMSE for Type A targets was 6.5 m; for Type B, 4.0 m. The difference in accuracy of the discretely digitized points (3.3 m) and the continuously digitized points (6.5 m and 4.0 m) is explainable in two ways.

In Type A the machine is digitizing while the operator is physically moving the platen. Hence, operator error must be slightly greater. In the case of Type B, at least for one of the lines, the operator is momentarily at rest at either the start or end of the line.

The second reason for the greater accuracy of the discretely digitized points is concerned with how often the machine captures a digit. For the test maps the digitizers collected a digit every 0.3 mm at model scale, which corresponds to every 12 m on the ground. It seems totally reasonable that the error for a Type A continuously digitized

Table 1. Error Contribution of the Digitizing Process in Metres at Ground Scale

	Gross RMSE	Internal Accuracy of Aerotriangulation	Digitizing Error
Test 1	4.00	1.64	3.65
Test 2	3.94	1.11	3.78
Test 3	3.07	1.03	2.89
Test 4	3.18	1.47	2.82

Average = 3.28 m.

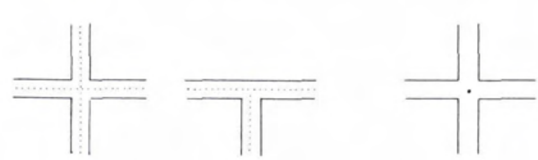

Fig. 1. All test points were digitized as individual, discrete points. Thirty-two points (Type A or B) were also continuously digitized.

point should be 6.5 m if a digit is captured only every 12 m.

This emphasizes the important fact that a mapping organization could be led to a false sense of accuracy if it only examines and compares individually digitized points.

As a corollary to the above fact, the question arises whether an organization, which is comparing its accuracy to the National Map Accuracy Standards, should compare the standards against discretely or continuously digitized points.

Output Subsystem Error

The planimetric digitized positions of the approximately 240 points dispersed over the four test maps were now stored. The computer controlling the output subsystem was instructed to output the points onto Kodak Kodalith MP estar base contact film at a scale of 1:50,000. The four pieces of film were contacted to Dupont CPF 7 cronopaque, which was placed in the same environment as the original film and given three days to acclimate.

The location of each test point on the cronopaque was measured with an optical line follower (OLF), a component of the Automap system as designed by Systemhouse. The accuracy of the OLF was measured several times, leading to the conclusion that, when used to measure a circular target by adopting the average of five positionings of a line in the center of the target (independently for both X and Y), it is accurate to 20 μm at table scale. This degree of inaccuracy, although small, was statistically removed from the output subsystem errors so as to not prejudice the system.

The operator of the OLF established an arbitrary origin in the approximate center of the cronopaque test map. Five readings in both X and Y were made on each of the approximately 60 test points found on the four test maps. "Truth" was taken as the digits captured and stored during the data acquisition (digitizing) phase. The X, Y readings from the OLF were corrected for measuring errors, then fit to "truth" through a least-squares application of a linear conformal transformation. The RMSE for each test sheet is shown in Table 2. Once again

Table 2. Output Subsystem RMSE for Each Test Sheet. All Units Are Metres

	Gross RMSE	OLF Measuring Error	Output Error
Test 1	2.02	1.00	1.76
Test 2	2.01	1.00	1.74
Test 3	2.24	1.00	2.00
Test 4	2.23	1.00	1.99

Average = 1.87 m.

RMSE = $[\Sigma V^2/(n - 1)]^{1/2}$ where $V^2 = (DX^2 + DY^2)$ and DX and DY represent "truth" (digitized coordinates) minus the measured coordinates on the test maps.

The value, 1.87 m, at ground scale is the best estimate for the size of the resulting error when instructing the output subsystem to place stored X, Y coordinates onto film. This value is independent of scale and may be converted to an error at table scale of 0.037 mm. This agrees favorably with the manufacturer's published accuracy of the output subsystem, which is 0.038 mm.

Conclusion

Under the conditions found at the Army Survey Regiment, Bendigo, Australia, the computer associated digitizing and automated output errors were 3.28 m and 1.87 m, respectively. It is also apparent that mapping organizations must address the problem whether to reference discretely or continuously digitized points when comparing their mapping accuracy to the National Map Accuracy Standards.

References

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