Bausch and Lomb Undergraduate Award

Evaluation of a Tablet Digitizer for Analytical Photogrammetry

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INTRODUCTION

Land Information Systems (LIS) contain vast amounts of data and can have many applications. Data within an LIS may include ownership boundaries, topography, runoff, soil erosion, landcover type, and so on. For most applications, ground coordinated data are needed. Various accuracies may suffice depending upon the type of data and its purpose. These ground coordinates can be determined by several different methods. One method might be a field survey. Another method is photogrammetry—using aerial photography with proper aerotriangulation software.

Various methods may be used to measure photo coordinates. Using a comparator, one can obtain photo coordinates to the nearest micrometre. However, a comparator can cost up to $50,000 or more, and many firms may not be able to afford this expensive investment. A tablet digitizer is an alternate possibility. This device costs approximately $2000, which is very inexpensive compared to the comparator. A tablet digitizer is also very convenient, is simple to use, and produces results quickly.

Questions may arise as to whether tablet digitizers would be saving money at the expense of losing too much accuracy. The goal of this research was to assess the accuracies that can be obtained by using a tablet digitizer as a basic measuring instrument for computing ground coordinates by aerotriangulation.

PROJECT BACKGROUND INFORMATION AND OVERVIEW

Several years ago the Wisconsin Department of Transportation (DOT) established an aerial photogrammetric test area. This was done on Bong Air Force Base, an abandoned facility in southern Wisconsin. The DOT established a network of ground control points in a dense configuration. Their X and Y ground coordinates were established by electronic traverse, while their Z coordinates (elevations) were determined by precise leveling. The purpose of establishing the test area was to evaluate accuracies of various photogrammetric systems.

The area has been photographed at various flying heights and with many different cameras. Prior to photography, control points were covered with cross-shaped panels. These "targets" allowed the control points to be visible on the photo.

For this research a strip of nine photos from the Bong Test area taken at a flying height of 2000 feet was used. The configuration of ground control points appearing on this test strip is shown in Figure 1.

Photo coordinates were measured using the tablet digitizer and processed through aerotriangulation software which included a bundle adjustment. Results from this were then compared with those obtained using a one-micrometre comparator and to a field survey. An analysis of these comparisons is given.

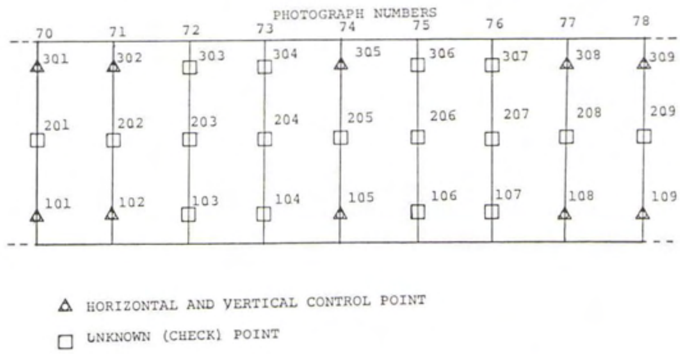

Fig. 1. Line of photos 70 to 78 from the Bong Test Project.

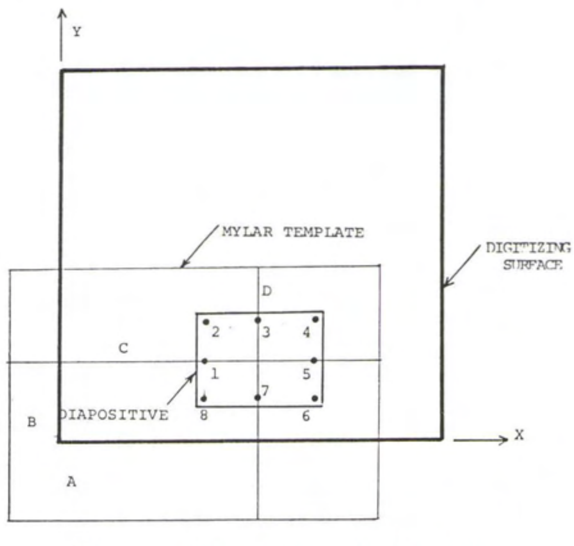

Fig. 2. Digitizer and placement of diapositive.

DIGITIZING THE PHOTOS

For this project, a 20-inch square tablet digitizer was used to measure the photo coordinates. Manufacturers of the tablet digitizer report a resolution of 0.001 inches and accuracy to the nearest 0.01 inch. The measuring surface is translucent and has been mounted on a frame. The surface has been illuminated from beneath by fluorescent lighting. This enhances the ability to measure photo coordinates from film diapositives accurately. The digitizer axes, as illustrated in Figure 2, were the left edge (y-axis) and the bottom edge (x-axis).

A digitizing program allowed all "acceptable" measured photo coordinates to be placed in a data file. Each photo measured had an individual data file. Each point on every photo was digitized five separate times, and standard deviations in the x-axis and y-axis directions were calculated. The program prompts the user to establish a rejection limit for the standard deviations. If the standard deviations are within the specified limits, the point is "accepted." Otherwise, the computer made a beeping sound to signify rejection. The point would then be remeasured. For this research a rejection limit of 0.003 inches was used. One photo was placed on the digitizer at a time and photo coordinates of all ground control points appearing on the photo were measured. Fiducials were also measured.

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TABLE 1. TABLET DIGITIZER VS. COMPARATOR (PHOTO COORDINATES)

PHOTO	PT	DIGITIZER (in mm) x	DIGITIZER (in mm) y	COMPARATOR (in mm) x	COMPARATOR (in mm) y	DIFF (x) (in mm)	DIFF (y) (in mm)	RMS (x) (in mm)	RMS (y) (in mm)
70	101	−7.634	−91.106	−7.516	−91.201	−0.118	0.095	0.156	0.067
	201	−1.739	1.700	−1.526	1.735	−0.213	−0.035		
	301	3.916	89.354	4.127	89.454	−0.211	−0.100		
	102	84.188	−92.869	84.331	−92.905	−0.143	0.036		
	202	90.003	−1.213	90.039	−1.170	−0.036	−0.043		
	302	96.172	85.050	96.316	84.988	−0.144	0.062		
71	101	−103.186	−91.087	−103.243	−91.179	0.057	0.092	0.113	0.074
	201	−97.875	1.855	−97.959	1.858	0.084	−0.003		
	301	−94.227	89.575	−94.146	89.649	−0.081	−0.074		
	102	−10.089	−91.156	−10.027	−91.239	−0.062	0.083		
	202	−5.491	0.237	−5.383	0.251	−0.108	−0.014		
	302	−0.418	86.198	−0.292	86.165	−0.126	0.033		
	103	80.631	−91.901	80.741	−91.958	−0.110	0.057		
	203	84.146	−1.305	84.366	−1.333	−0.220	0.028		
	303	88.384	83.372	88.460	83.218	−0.076	0.154		
72	102	−87.273	−93.719	−87.323	−93.944	0.050	0.225	0.105	0.123
	202	−82.952	−1.927	−82.869	−1.995	−0.083	0.068		
	302	−78.149	83.328	−78.190	83.345	0.041	−0.017		
	103	4.481	−93.725	4.576	−93.895	−0.095	0.170		
	203	7.829	−2.535	7.978	−2.607	−0.149	0.072		
	303	11.185	81.638	11.196	81.565	−0.011	0.073		
	104	94.941	−93.639	95.063	−93.766	−0.122	0.127		
	204	96.974	−3.116	97.166	3.196	−0.192	0.080		
	304	99.609	80.445	99.676	80.306	−0.067	0.139		
73	103	−84.378	−88.145	−84.404	−88.308	0.026	0.163	0.092	0.101
	203	−80.372	1.114	−80.375	1.108	0.003	0.006		
	303	−77.135	85.776	−77.251	85.761	0.116	0.015		
	104	4.957	−90.092	5.093	−90.254	−0.136	0.162		
	204	8.919	0.186	9.039	0.150	−0.120	0.036		
	304	12.622	85.807	12.672	85.760	−0.050	0.047		
	105	96.484	−92.083	96.588	−92.244	−0.104	0.161		
	205	100.434	−0.769	100.474	−0.807	−0.040	0.038		
	305	104.618	85.840	104.735	85.751	−0.117	0.089		
74	104	−91.573	−92.571	−91.512	−92.822	−0.061	0.251	0.080	0.178
	204	−87.113	−1.805	−87.147	−1.901	0.034	0.096		
	304	−83.845	82.979	−83.865	82.850	0.020	0.129		
	105	−0.697	−93.935	−0.601	−94.142	−0.096	0.207		
	205	2.831	−2.333	2.901	−2.423	−0.070	0.090		
	305	6.037	83.229	6.144	83.063	−0.107	0.166		
	106	91.843	−95.350	91.895	−95.505	−0.052	0.155		
	206	94.401	−2.873	94.515	−2.958	−0.114	0.085		
	306	97.601	83.616	97.703	83.319	−0.102	0.297		
75	105	−94.281	−93.824	−94.239	−94.036	−0.042	0.212	0.100	0.151
	205	−90.287	−2.163	−90.284	−2.270	−0.003	0.107		
	305	−87.141	83.283	−87.169	83.202	0.028	0.081		
	106	−2.599	−93.932	−2.502	−94.121	−0.097	0.189		
	206	0.448	−2.316	0.544	−2.404	−0.096	0.088		
	306	3.391	83.211	3.496	83.042	−0.105	0.169		
	107	89.002	−94.044	89.051	−94.215	−0.049	0.171		
	207	91.377	−2.407	91.487	−2.525	−0.110	0.118		
	307	93.779	82.985	93.989	82.817	−0.210	0.168		
76	106	−90.497	−90.667	−90.566	−90.891	0.069	0.224	0.083	0.144
	206	−87.386	−0.257	−87.458	−0.238	0.072	−0.019		
	306	−85.009	85.625	−84.977	85.608	−0.032	0.017		
	107	−0.053	−90.869	−0.016	−91.064	−0.037	0.195		
	207	3.163	−0.307	3.249	−0.384	−0.086	0.077		
	307	5.827	85.564	6.006	85.425	−0.179	0.139		
	108	90.642	−91.089	90.663	−91.204	−0.021	0.115		
	208	93.951	−0.386	94.041	−0.507	−0.090	0.121		
	308	97.089	85.498	97.126	85.289	−0.037	0.209		
77	107	−90.552	−94.324	−90.528	−94.495	−0.024	0.171	0.064	0.115
	207	−86.161	−3.156	−86.172	−3.242	0.011	0.086		
	307	−83.037	81.431	−83.023	81.377	−0.014	0.054		
	108	0.668	−94.757	0.720	−94.890	−0.052	0.133		
	208	3.795	−3.322	3.859	−3.455	−0.064	0.133		
	308	6.689	81.390	6.789	81.335	−0.100	0.055		
	109	92.236	−95.175	92.239	−95.302	−0.003	0.127		
	209	94.315	−3.559	94.384	−3.656	−0.069	0.097		
	309	96.871	81.399	96.992	81.272	−0.121	0.127		
78	108	−92.146	−99.522	−92.036	−99.592	−0.110	0.070	0.092	0.061
	208	−87.796	−7.246	−87.850	−7.348	0.054	0.102		
	308	−83.874	76.147	−83.905	76.177	0.031	−0.030		
	109	−0.067	−99.509	0.019	−99.506	−0.086	−0.003		
	209	2.341	−6.764	2.462	−6.819	−0.121	0.055		
	309	4.591	77.114	4.703	77.059	−0.112	0.055		

The same area on the digitizer was used for each photo measured (see Figure 2). This was accomplished by using a mylar template. Lines C and D of the template passed through opposite fiducial marks 1 and 5, and 3 and 7, respectively. It was also ensured that lines A and B coincided with the y-axis and x-axis, respectively, of the digitizing surface. This was done so that potentially the measured photo coordinates could later be processed through refinement software.

PROCESSING THE DATA

The DOT camera used for this project contained eight fiducial marks—four side and four corner. As noted above, these were also digitized into a photo's data file. With this data file of measured photo coordinates, and a file of the camera's eight calibrated fiducial axis coordinates, all nine photos were processed through an affine coordinate transformation to place the measured photo coordinates in their respective fiducial axis systems.

After this, each individual photo was processed through a space resection program to solve for its six camera orientation parameters (omega, phi, kappa, X_c, Y_c, Z_c). Omega, phi, and kappa are rotation angles that define the orientation of the photo, while X_c, Y_c, and Z_c are the ground based coordinates of each exposure station. These values were used as initial approximations for processing the data through a bundle adjustment.

For the bundle adjustment, ten control points in the strip of photos (see Figure 1) were selected, four on each end, and two in the middle. All other control points were treated as unknowns and thus served as "check points." The focal length of the camera was precisely known; and, as previously stated, camera orientation parameters obtained from space resection was used as initial approximations for the bundle adjustment. Based upon the results from the field survey, initial approximations for the ground coordinates of the unknown points were made. These data, together with the transformed photo coordinates, were processed through a bundle adjustment for the entire strip.

ANALYSIS OF RESULTS

Results of the bundle adjustment are given in Tables 1 and 2. Table 1 lists tablet digitizer refined photo coordinates and photo coordinates that were obtained with a one-micrometre comparator. Discrepancies between the sets of values are tabulated and root-mean-square (RMS) values of the differences are also listed for each photo. Mean RMS values are the following:

$$\text{RMS}(x) = 0.098 \text{ mm} \qquad \text{RMS}(y) = 0.113 \text{ mm}$$

Table 2 contains the results of ground coordinates of check points computed by the bundle adjustment, and compares them to their ground surveyed values. Discrepancies are tabulated. The standard deviations in the differences between the bundle adjustment ground coordinates and field survey ground coordinates are the following:

$$\text{RMS}(X) = 0.461 \text{ ft.} \quad \text{RMS}(Y) = 0.612 \text{ ft.} \quad \text{RMS}(Z) = 1.105 \text{ ft.}$$

CONCLUSION

For many LIS applications, the accuracies demonstrated above in computed X, Y, and Z ground coordinates are quite suitable. Where the boundaries do not have to be exactly defined, such as wetland areas, land cover, and so on, these results are more than adequate.

It is acknowledged that, for some applications, the demonstrated standard deviations in computed ground coordinates are too large. However, calibration of the tablet digitizer in a further study could improve these results. For this calibration, a fine precise grid could be placed on the same digitizing area as that on which the photos were measured. Intersection points on the grid could be measured. Differences between the precisely known values and the measured values could be calculated. These differences could be fitted to a correction polynomial and through its use, refined coordinates obtained. These coordinates would in all probability yield better results in the bundle adjustment.

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TABLE 2. BUNDLE ADJUSTMENT VS. FIELD SURVEY (GROUND COORDINATES)

POINT	DIGITIZER (in feet) X	Y	Z	GROUND SURVEY (in feet) X	Y	Z	DIFF (X)	DIFF (Y) (in feet)	DIFF (Z)
103	89899.41	5450.05	800.97	89899.82	5450.00	801.23	−0.41	0.05	−0.26
104	90799.13	5449.78	800.04	90799.90	5449.99	800.18	−0.77	−0.21	−0.14
106	92600.19	5450.43	800.46	92600.22	5449.94	799.60	−0.03	0.49	0.86
107	93499.66	5450.35	800.29	93499.64	5449.89	799.91	0.03	0.46	0.38
201	88129.10	6350.28	808.09	88129.56	6350.15	810.24	−0.46	0.13	−2.15
202	89029.71	6349.79	806.95	89029.82	6350.16	804.62	−0.11	−0.37	2.33
203	89928.01	6349.70	794.41	89928.75	6350.19	795.84	−0.74	−0.49	−1.43
204	90829.35	6349.71	794.35	90829.58	6350.22	795.87	−0.23	−0.51	−1.52
205	91729.90	6349.67	797.33	91729.51	6350.27	796.56	0.39	−0.60	0.77
206	92628.71	6349.58	795.74	92628.84	6350.33	796.28	−0.13	−0.74	−0.54
207	93530.61	6350.12	796.35	93530.63	6350.39	796.55	−0.02	−0.27	−0.20
208	94429.30	6350.38	801.57	94429.19	6350.46	802.64	0.11	−0.08	−1.07
209	95329.09	6349.91	796.94	95329.43	6350.53	796.15	−0.36	−0.62	0.79
303	89956.87	7200.07	801.85	89956.05	7198.95	803.35	0.82	1.13	−1.50
304	90856.81	7199.38	802.51	90856.21	7198.84	803.35	0.60	0.54	−0.84
306	92656.62	7199.86	802.87	92657.11	7198.62	803.54	−0.49	1.24	−0.67
307	93555.84	7199.57	802.43	93556.51	7198.51	803.14	−0.67	−1.06	−0.71
				MEAN RMS VALUES :			0.461	0.612	1.105