Department of the Interior
US Geological Survey

USGS QUALITY ASSURANCE PLAN FOR DIGITAL AERIAL IMAGERY:

RANGE VALIDATION: CITY OF SIOUX FALLS AND MINNEHAHA AND LINCOLN COUNTIES

DRAFT for Review

14 August 2009

science for a changing world

DIGITAL AERIAL SENSOR TYPE CERTIFICATION

(Draft for Review)

14Aug 2009

Written By:

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Aparajithan Sampath 14 Aug 2009
Sr. Photogrammetrist, SGT, Inc.
Contractor to the USGS EROS

Approved By:

_____

Greg Stensaas Date
Project Chief
Remote Sensing Technologies Project
US Geological Survey, EROS Center

USGS EROS Data Center
Sioux Falls, South Dakota

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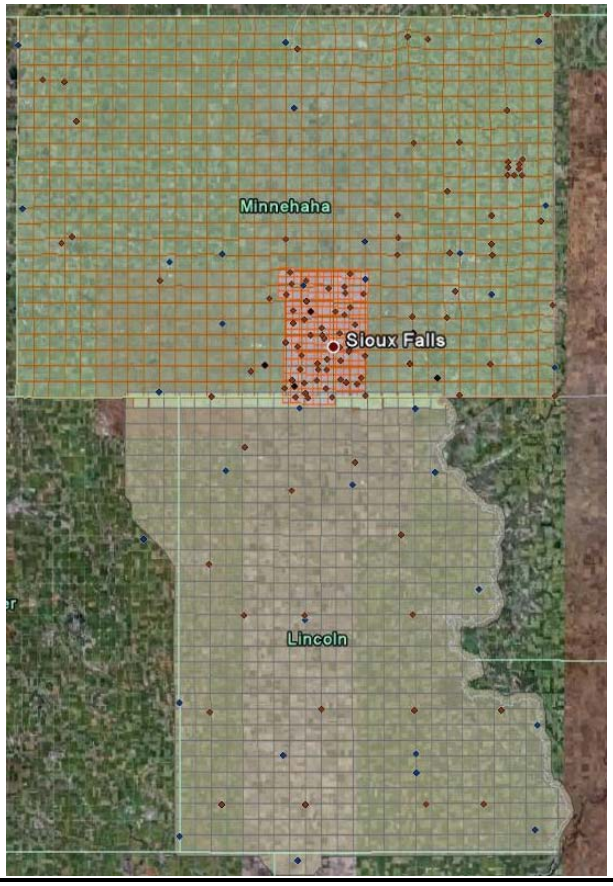


1 Purpose

The purpose of the survey was to determine the suitability of the use of Sanborn orthophoto data products for Sioux Falls range validation.

The suitability was assessed by determining the accuracy of orthophotos generated by Sanborn LLC over Minnehaha and Lincoln counties. The orthophotos were generated at three different ground sample distances: 3”, 6” and 12”. A total of 112 photo identifiable points were selected from the orthophotos, and were surveyed using GPS-RTK surveying techniques. In areas where the point density was less, surveyed points on painted targets were used. Root mean square error (RMSE) values were generated for these points using Accuracy Analyst™ software.

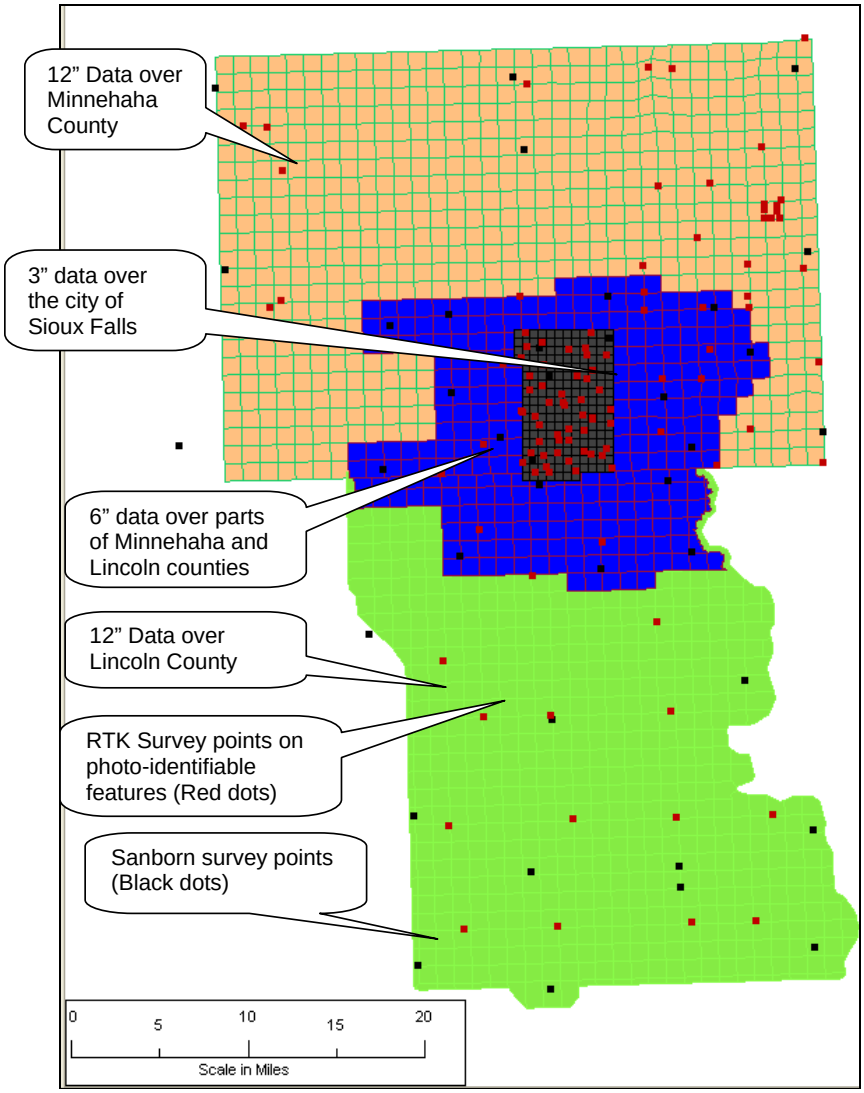


Figure 1: The three different resolutions of orthophotos over Minnehaha 12” (Orange), Lincoln 12” (Green), Sioux Falls 6” (Blue) and Sioux Falls 3” (Black) and the survey point distribution

2 Methodology

2.1 GPS-RTK Survey

The GPS survey consisted of two steps. In the first step, photo-identifiable points were selected from the images, using ArcMap and ENVI software. The points were picked such that they are well distributed over the entire area. An attempt was made to pick points from different kinds of terrain. However, a lack of sharp photo-identifiable features, particularly in rural areas prevented this. The points were picked on uniform slopes, or flat regions.

In the next step, GPS-RTK (Real Time Kinematic) survey method was used to determine the coordinates of these photo-identifiable points. The RTK survey uses two GPS receivers. One of the receivers, called the base station, is placed over a control point. The other, called the rover, is used to determine the coordinates of unknown points. The base station receiver was a Topcon receiver with a Pacific Crest radio, and the rover was a Topcon receiver of dual-frequency Hiper+ type (see Figure 2). The rover receives pseudo-range corrections from the base station receiver for coordinate measurements that it makes using data received from GPS satellites.

Figure 2: Hiper + rover set up over a painted target near Joe Foss Field

The control points for the base station locations were selected and retrieved from the NGS (http://www.ngs.noaa.gov/cgi-bin/ds_pid.prl). Only first-order horizontal points reported as “suitable for satellite observations” were used to initialize the base station. Generally, these points had reported accuracy estimates of 0.5 – 0.7 cm (at 95% confidence level).

The GPS-RTK survey process was tested by placing the rover over previously surveyed points. These previously surveyed points are aerial photo targets over Joe Foss Field in Sioux Falls. The base station receiver was placed over a control point at EROS that had been previously established by static occupation. The results of the survey are presented in Table 1. Since the orthophotos are in UTM Zone 14 N, with distance units in feet, the survey coordinates were also determined in the same system (All distances in Table 1 are in feet).

Table 1: RTK Survey test of Joe Foss Field, with base station receiver at EROS

Point ID	Published Y	Published X	Measured Y	Measured X	Error (Distance-ft)
119	15845074.170	2241404.041	15845074.107	2241404.105	0.090
120	15845371.700	2240818.254	15845371.588	2240818.250	0.112
121	15845668.660	2240224.570	15845668.656	2240224.605	0.035
122	15845961.310	2239639.755	15845961.267	2239639.769	0.045
123	15846257.100	2239046.513	15846257.101	2239046.641	0.128
124	15845988.130	2238526.175	15845988.102	2238526.148	0.039
125	15845709.080	2237784.810	15845709.150	2237784.882	0.101
126	15845331.330	2237249.620	15845331.382	2237249.680	0.079
127	15844954.410	2236715.474	15844954.486	2236715.533	0.096
128	15844571.200	2236183.651	15844571.229	2236183.683	0.043

129	15843933.390	2236029.587	15843933.379	2236029.674	0.088
130	15843379.210	2236388.966	15843379.254	2236388.984	0.047
131	15842841.500	2236764.653	15842841.526	2236764.589	0.069
132	15842203.780	2236918.192	15842203.792	2236918.199	0.013
134	15841662.970	2236531.672	15841662.850	2236531.660	0.120
				Mean Error	0.074 ft

The city of Sioux Falls also maintains a Continuously Operating Reference Station (CORS) and two other GPS receiver stations, any of which can be used as a base station. The accuracy of the GPS-RTK survey using these receivers was also tested, and the results are shown in Table 2.

Table 2: Test of RTK survey using base station receivers at CORS station

Point ID	Published Y	Published X	Measured Y	Measured X	Error (Distance-ft)
119	15845074.170	2241404.041	15845074.161	2241404.038	0.010
119	15845074.170	2241404.041	15845074.194	2241404.052	0.027
121	15845668.660	2240224.570	15845668.644	2240224.529	0.044
122	15845961.310	2239639.755	15845961.301	2239639.718	0.038
OQ1033	15905732.433	2226521.820	15905732.360	2226521.866	0.086
				Mean Error	0.041 ft

It can be seen that the accuracy indicated by both of the tests (a maximum error of 0.12 ft, or 3.65 cm) is acceptable to test orthophotos with GSDs of 3”, 6”, and 12”.

Either of the two different methods for RTK surveying was used, depending on the conditions and requirements of each survey. Base station receivers over known locations were set up to survey rural areas in Minnehaha and Lincoln counties. This system was used when NGS control points with sub-centimeter accuracy were readily available, and the surrounding terrain was fairly flat. The operating range of this system was limited by the range of the radio link, and was typically around 12 miles with little relief and 4 miles with major relief.

In an urban area like Sioux Falls it could be troublesome, dangerous, or inefficient to set up base stations. It was far easier and more productive to use the existing CORS network for RTK surveying. Again, this system was limited by the range of the radio link, but because of the elevated position and power of the CORS antennas, the effective range was around 20 miles. This made it extremely convenient to survey Sioux Falls extensively, and was well-suited to the stop-and-go nature of urban surveying.

However, it should be noted that as the distance from the base station increases, the accuracy of the RTK rover coordinates may decrease. This is because the corrections to pseudo-range measurements that it transmits to the rover may not be applicable over large distances. However, the CORS receiver in Sioux Falls was used to obtain a rover coordinate measurement over the control point at EROS, and the accuracy was 0.054 ft.

As an aid in moving from one survey location (photo-identifiable point) to another, a road map of the Minnehaha and Lincoln counties was downloaded from the US Census bureau, and ArcMap was used to generate optimal driving directions between these points (see Figure 3).

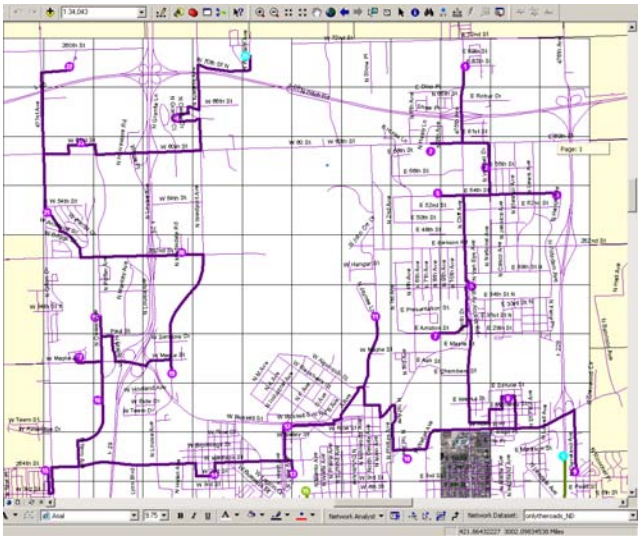


Figure 3: Determining a route in ArcMap

Close-up and contextual ground photographs were taken at each survey location (See Appendix A). These are not only a record of the survey conditions, but also aid in the final accuracy assessment, as they help avoid gross errors/blunders.

The region covered by the 3” dataset was surveyed extensively, with a total of 56 points taken in an approximately 45 square mile area. In addition, several regions of large elevation change were targeted, mainly because the control points used to initially correct the imagery had all been located in flat areas. The 6” image set was also surveyed completely and 13 points exclusive to the 6” area were used. However, because the 6” area covered the 3” area, we were able to use the same surveyed locations and simply re-pick the image points from the 6” set, bringing the point total to 69.

The 1’ dataset are actually a mosaic of two products. Parts of these data were resampled from the 6” data and the remaining parts were collected at 1’ GSD. The dataset covers areas covered by both the 3” and the 6” datasets, which allowed all previously surveyed locations to be used. The point total was 112. Because of time constraints, distance, and sparse control points (photo-identifiable as well as base station) it was not practical to survey the 1’ data to the same extent as the smaller 3” and 6” sets. Instead, we obtained a full set of points in the eastern third and the southern fourth of the county.

2.2 Accuracy assessment

The accuracy of the orthophotos was measured using the Accuracy Analyst™ software. The software provides a quick and easy way to assess the accuracy of orthophotos. The assessment was made for the three different GSD separately. The summary of the report is presented below, and the complete report is given in Appendix A.

Table 3: Comparison of survey points and photo coordinates over the 3" GSD data. All measurements are in feet.

ID	X(survey, ft)	Y(survey, ft)	X(photo, ft)	Y(photo, ft)	ΔX (ft)	ΔY (ft)
SF3-1	2233700.69	15809311.54	2233700.98	15809311.54	0.29	0.00
SF3-3	2229580.72	15809471.42	2229581.24	15809471.50	0.52	0.08
SF3-4	2241749.61	15809784.40	2241750.00	15809784.01	0.40	-0.39
SF3-5	2252793.91	15810588.08	2252793.50	15810588.00	-0.41	-0.09
SF3-6	2232866.91	15810889.41	2232867.22	15810889.26	0.31	-0.15
SF3-7	2225864.51	15812355.61	2225865.01	15812355.51	0.50	-0.11
SF3-8	2239559.83	15812607.54	2239559.75	15812607.26	-0.08	-0.28
SF3-9	2239590.23	15812647.01	2239590.12	15812646.63	-0.11	-0.38
SF3-10	2232299.50	15814271.29	2232299.61	15814271.12	0.11	-0.17
SF3-12	2246279.09	15814783.91	2246279.00	15814783.76	-0.09	-0.15
SF3-13	2228363.95	15815073.47	2228364.47	15815073.24	0.52	-0.22
SF3-14	2236481.73	15815206.20	2236481.73	15815206.03	0.00	-0.17
SF3-15	2244429.04	15815739.68	2244428.75	15815739.51	-0.29	-0.17
SF3-16	2251204.87	15816522.88	2251204.25	15816522.78	-0.62	-0.10
SF3-17	2230865.22	15818734.77	2230865.23	15818734.52	0.02	-0.25
SF3-18	2239694.91	15818852.40	2239694.99	15818852.26	0.08	-0.14
SF3-19	2236874.94	15818855.77	2236875.00	15818855.76	0.06	-0.01
SF3-21	2236601.51	15820895.75	2236601.5	15820895.51	-0.01	-0.24
SF3-22	2244258.90	15821980.82	2244258.75	15821981.02	-0.15	0.19
SF3-23	2239702.74	15822392.21	2239702.5	15822392.25	-0.23	0.05
SF3-24	2231189.95	15823425.00	2231190.00	15823424.75	0.06	-0.24
SF3-25	2252333.98	15823888.53	2252333.50	15823888.27	-0.48	-0.26
SF3-26	2246892.50	15825141.54	2246892.5	15825141.76	0.00	0.22
SF3-27	2246971.04	15825636.52	2246969.85	15825636.38	-1.19	-0.14
SF3-28	2229838.36	15826305.94	2229838.49	15826305.77	0.13	-0.17
SF3-29	2243864.72	15826406.79	2243864.27	15826406.77	-0.46	-0.02
SF3-30	2225768.92	15827497.37	2225769.25	15827497.51	0.33	0.14
SF3-31	2225762.08	15827645.96	2225762.49	15827645.77	0.41	-0.18
SF3-32	2252183.74	15828346.70	2252183.24	15828346.53	-0.49	-0.17
SF3-33	2252105.47	15828391.88	2252104.74	15828391.51	-0.73	-0.37
SF3-34	2238584.29	15829324.58	2238584.50	15829324.51	0.21	-0.07
SF3-35	2238580.70	15829446.52	2238580.49	15829446.02	-0.21	-0.50
SF3-36	2233977.47	15830261.50	2233977.49	15830261.26	0.02	-0.23
SF3-37	2237921.96	15830303.67	2237921.76	15830303.49	-0.20	-0.17
SF3-38	2243700.03	15831082.83	2243700.01	15831083.00	-0.02	0.17
SF3-39	2237654.08	15832740.45	2237654.25	15832740.51	0.17	0.06
SF3-40	2228095.53	15834057.31	2228096.00	15834057.53	0.47	0.22
SF3-41	2248771.30	15834137.06	2248771.24	15834136.77	-0.05	-0.29
SF3-42	2245105.28	15837298.17	2245105.48	15837298.25	0.20	0.08
SF3-43	2227966.35	15838287.26	2227966.70	15838287.25	0.36	-0.01
SF3-44	2242093.83	15838311.77	2242094.25	15838311.76	0.42	-0.01
SF3-45	2246956.17	15839847.69	2246955.74	15839847.26	-0.44	-0.43
SF3-46	2232326.12	15841541.98	2232326.49	15841542.26	0.37	0.28
SF3-47	2225562.90	15843582.18	2225563.26	15843582.27	0.36	0.10

SF3-48	2251229.47	15844448.67	2251228.99	15844448.52	-0.48	-0.14
SF3-49	2245227.82	15844552.07	2245227.74	15844552.27	-0.07	0.20
SF3-50	2239639.72	15845961.30	2239639.79	15845961.32	0.07	0.02
SF3-51	2244876.73	15846679.22	2244876.98	15846679.27	0.25	0.05
SF3-52	2227259.73	15847128.82	2227259.98	15847128.78	0.25	-0.04
SF3-53	2232013.27	15848351.70	2232013.50	15848351.76	0.23	0.06
SF3-54	2246632.58	15850990.30	2246632.74	15850990.26	0.16	-0.04
SF3-55	2226670.09	15851003.86	2226670.50	15851004.01	0.41	0.15
Mean ΔX =-0.02 ft Min ΔX =-1.19 ft Max ΔX =0.52ft RMSE ΔX=0.36 ft				Mean ΔY =-0.09 ft Min ΔY =-0.5 ft Max ΔY =0.28 ft RMSE ΔY=0.20 ft		
RMSE Ratio=0.56 CE90: 0.59 ft CE95: 0.67 ft						

Table 3 shows the comparison of the coordinates of photo-identifiable points between the 3" GSD orthophotos and the GPS-RTK survey. The last two rows of Table 3 show that the mean error is very small, which indicates that there is no systematic bias in the data. The RMSE indicates that 90% of the well defined points have an accuracy of at least 0.59 ft and that 95% of the points have an accuracy of at least 0.67 ft. The error distribution is shown in Figure 4. The blue cross indicates the error, and the red and the green circles indicate the regions for 90% and 95% circular error.

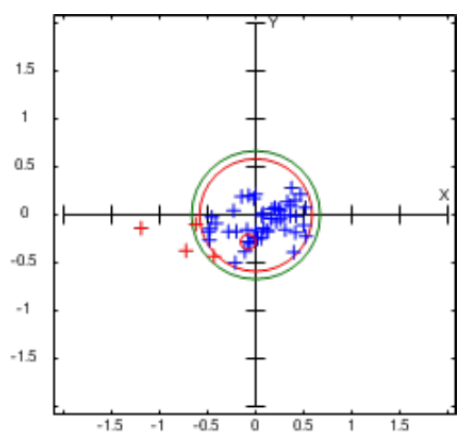


Figure 4: The circular error (CE) plot for Sioux Falls 3" GSD data (from Accuracy Analyst™)

Table 4: Comparison of survey points and photo coordinates over the 6" GSD data. All measurements are in feet.

SF3-1	2233700.69	15809311.54	2233700.51	15809311.44	-0.18	-0.10
SF3-3	2229580.72	15809471.42	2229580.97	15809471.06	0.25	-0.36
SF3-4	2241749.61	15809784.40	2241749.22	15809783.73	-0.39	-0.67
SF3-5	2252793.91	15810588.08	2252792.97	15810587.98	-0.94	-0.10
SF3-6	2232866.91	15810889.41	2232866.80	15810888.83	-0.11	-0.58
SF3-7	2225864.51	15812355.61	2225864.84	15812355.90	0.33	0.29
SF3-8	2239559.83	15812607.54	2239559.49	15812607.01	-0.33	-0.53
SF3-9	2239590.23	15812647.01	2239590.05	15812646.52	-0.17	-0.49
SF3-10	2232299.50	15814271.29	2232299.73	15814271.25	0.24	-0.04
SF3-12	2246279.09	15814783.91	2246279.04	15814783.56	-0.04	-0.35
SF3-13	2228363.95	15815073.47	2228364.77	15815072.96	0.82	-0.51
SF3-14	2236481.73	15815206.20	2236481.99	15815206.01	0.27	-0.19
SF3-15	2244429.04	15815739.68	2244428.98	15815739.51	-0.06	-0.17
SF3-16	2251204.87	15816522.88	2251204.49	15816522.81	-0.38	-0.07
SF3-17	2230865.22	15818734.77	2230865.19	15818734.52	-0.02	-0.25
SF3-18	2239694.91	15818852.40	2239694.87	15818852.13	-0.05	-0.27
SF3-19	2236874.94	15818855.77	2236874.99	15818856.01	0.05	0.24
SF3-21	2236601.51	15820895.75	2236601.52	15820895.53	0.01	-0.22
SF3-22	2244258.90	15821980.82	2244258.60	15821981.06	-0.30	0.24
SF3-23	2239702.74	15822392.21	2239702.46	15822392.54	-0.27	0.33
SF3-24	2231189.95	15823425.00	2231189.97	15823424.60	0.02	-0.04
SF3-25	2252333.98	15823888.53	2252333.28	15823888.77	-0.71	0.24
SF3-26	2246892.50	15825141.54	2246892.73	15825141.89	0.23	0.35
SF3-27	2246971.04	15825636.52	2246970.49	15825636.27	-0.55	-0.25
SF3-28	2229838.36	15826305.94	2229838.49	15826305.64	0.13	-0.30
SF3-29	2243864.72	15826406.79	2243864.24	15826406.40	-0.49	-0.39
SF3-30	2225768.92	15827497.37	2225769.51	15827497.52	0.59	0.15
SF3-31	2225762.08	15827645.96	2225762.99	15827645.76	0.92	-0.20
SF3-32	2252183.74	15828346.70	2252183.06	15828346.44	-0.67	-0.26
SF3-33	2252105.47	15828391.88	2252105.01	15828391.53	-0.46	-0.35
SF3-34	2238584.29	15829324.58	2238584.50	15829324.51	0.21	-0.07
SF3-35	2238580.70	15829446.52	2238580.52	15829446.13	-0.18	-0.39
SF3-36	2233977.47	15830261.50	2233977.34	15830261.15	-0.13	-0.35
SF3-37	2237921.96	15830303.67	2237921.50	15830303.30	-0.46	-0.37
SF3-38	2243700.03	15831082.83	2243699.84	15831082.80	-0.19	-0.03
SF3-39	2237654.08	15832740.45	2237653.83	15832740.22	-0.25	-0.23
SF3-40	2228095.53	15834057.31	2228096.00	15834057.50	0.47	0.19
SF3-41	2248771.30	15834137.06	2248771.29	15834136.72	-0.01	-0.34
SF3-42	2245105.28	15837298.17	2245105.51	15837298.00	0.23	-0.17
SF3-43	2227966.35	15838287.26	2227966.98	15838287.50	0.63	0.24
SF3-44	2242093.83	15838311.77	2242093.51	15838311.50	-0.32	-0.27
SF3-45	2246956.17	15839847.69	2246955.53	15839847.05	-0.65	-0.64
SF3-46	2252333.98	15823888.53	2252333.28	15823888.77	-0.71	0.24
SF3-47	2246892.50	15825141.54	2246892.73	15825141.89	0.23	0.35
SF3-48	2246971.04	15825636.52	2246970.49	15825636.27	-0.55	-0.25

SF3-49	2229838.36	15826305.94	2229838.49	15826305.64	0.13	-0.30
SF3-50	2243864.72	15826406.79	2243864.24	15826406.40	-0.49	-0.39
SF3-51	2225768.92	15827497.37	2225769.51	15827497.52	0.59	0.15
SF3-52	2225762.08	15827645.96	2225762.99	15827645.76	0.92	-0.20
SF3-53	2252183.74	15828346.70	2252183.06	15828346.44	-0.67	-0.26
SF3-54	2252105.47	15828391.88	2252105.01	15828391.53	-0.46	-0.35
SF3-55	2238584.29	15829324.58	2238584.50	15829324.51	0.21	-0.07
M6-2	2238580.70	15829446.52	2238580.52	15829446.13	-0.18	-0.39
M6-3	2233977.47	15830261.50	2233977.34	15830261.15	-0.13	-0.35
M6-4	2237921.96	15830303.67	2237921.50	15830303.30	-0.46	-0.37
M6-5	2243700.03	15831082.83	2243699.84	15831082.80	-0.19	-0.03
M6-6	2237654.08	15832740.45	2237653.83	15832740.22	-0.25	-0.23
M6-7	2228095.53	15834057.31	2228096.00	15834057.50	0.47	0.19
M6-8	2248771.30	15834137.06	2248771.29	15834136.72	-0.01	-0.34
M6-10	2245105.28	15837298.17	2245105.51	15837298.00	0.23	-0.17
M6-11	2227966.35	15838287.26	2227966.98	15838287.50	0.63	0.24
M6-12	2242093.83	15838311.77	2242093.51	15838311.50	-0.32	-0.27
M6-13	2246956.17	15839847.69	2246955.53	15839847.05	-0.65	-0.64
L6-1	2213141.04	15792326.87	2213140.77	15792327.29	-0.27	0.42
L6-2	2249967.67	15788332.10	2249968.14	15788331.91	0.47	-0.19
Mean ΔX =-0.04 ft Min ΔX =-0.94 ft Max ΔX =0.92ft RMSE ΔX =0.43 ft			Mean ΔY =-0.15 ft Min ΔY =-1.17 ft Max ΔY =0.42 ft RMSE ΔY =0.34 ft			
RMSE Ratio=0.79 CE90: 0.83 ft CE95: 0.95 ft						

Table 4 shows the results of comparing the orthophotos with the GPS-RTK survey for the 6” data set (Sioux Falls, parts of Southern Minnehaha and Northern Lincoln Counties). Since the 6” data subsumed the 3” data, the photo-identifiable points picked from the 3” data were used whenever possible for the analysis.

The mean error in the X and the Y indicates that there may be a small bias of -0.15 ft in the Y direction. The RMSE indicates that 90% of the well defined points have an accuracy of at least 0.83 ft and that 95% of the points have an accuracy of at least 0.95 ft. The error distribution is shown in Figure 5. Considering that the pixel size is 0.5 ft, these values lie between 1.6-2 pixels.

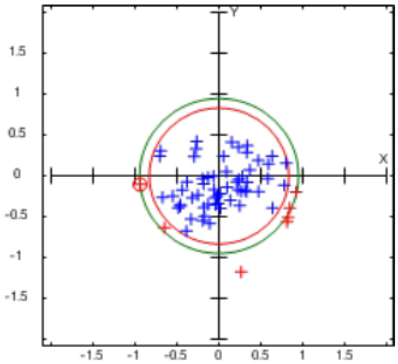


Figure 5: The circular error (CE) plot for Sioux Falls 6" GSD data (from Accuracy Analyst™). The blue cross indicates the error, and the red and the green circles indicate the regions for 90% and 95% circular error.

Table 5: Comparison of survey points and photo coordinates over the 12" GSD data over Minnehaha County. All measurements are in feet

ID	X(survey, ft)	Y(survey, ft)	X(photo, ft)	Y(photo, ft)	ΔX (ft)	ΔY (ft)
M12-1	2300471.91	15885309.07	2300472.25	15885309.64	0.34	0.57
M12-2	2298184.77	15885331.44	2298184.37	15885331.51	-0.40	0.07
M12-3	2303014.81	15885353.22	2303014.52	15885352.64	-0.29	-0.58
M12-4	2301931.60	15887485.72	2301931.07	15887485.86	-0.53	0.14
M12-5	2298422.69	15887888.37	2298422.75	15887887.88	0.05	-0.49
M12-6	2302062.78	15889050.82	2302062.42	15889050.08	-0.35	-0.74
M12-7	2298323.51	15889680.80	2298323.45	15889679.62	-0.06	-1.18
M12-1	2297528.83	15906877.52	2297528.96	15906878.04	0.14	0.52
M12-1	2270535.98	15929916.54	2270536.35	15929916.27	0.37	-0.27
M12-1	2314359.87	15842385.88	2314361.17	15842384.83	1.30	-1.05
M12-1	2315882.70	15812175.13	2315882.01	15812175.66	-0.69	0.53
M12-1	2293810.54	15858542.97	2293810.81	15858543.55	0.28	0.58
M12-1	2309819.20	15870321.75	2309819.98	15870322.52	0.77	0.77
M12-1	2278334.13	15879436.19	2278334.47	15879435.56	0.34	-0.63
M12-1	2266690.22	15895197.23	2266690.79	15895196.54	0.57	-0.69
M12-1	2281853.61	15895804.23	2281854.19	15895802.99	0.58	-1.24
M12-1	2263724.95	15930653.36	2263724.45	15930652.62	-0.51	-0.74
M12-2	2294139.97	15822185.50	2294140.37	15822185.66	0.40	0.16
M12-2	2261900.70	15871013.49	2261900.25	15871014.18	-0.45	0.69
M12-2	2293288.09	15871641.75	2293287.49	15871642.77	-0.61	1.02
M12-2	2293390.79	15862204.52	2293391.32	15862204.49	0.53	-0.03
M12-2	2153705.45	15860890.70	2153703.99	15860891.21	-1.46	0.51
M12-2	2149698.92	15912446.69	2149698.59	15912446.95	-0.33	0.26
M12-2	2142525.04	15913048.60	2142524.44	15913048.67	-0.59	0.07
M12-3	2154097.53	15899441.08	2154096.46	15899441.07	-1.07	-0.01
M12-3	2150290.48	15858688.93	2150288.99	15858688.83	-1.49	-0.10
M12-3	2227086.93	15925584.38	2227087.18	15925583.64	0.25	-0.74
M6-1	2284121.81	15811590.22	2284120.67	15811591.32	-1.14	1.10
M6-2	2267286.45	15821642.37	2267287.16	15821641.64	0.71	-0.73
M6-3	2267761.74	15837279.76	2267761.62	15837279.33	-0.12	-0.43
M6-4	2279241.56	15837283.15	2279240.15	15837283.10	-1.41	-0.05
M6-5	2281843.28	15846096.37	2281844.28	15846095.74	1.00	-0.63
M6-6	2262197.50	15857776.20	2262197.55	15857776.70	0.05	0.50
M6-7	2279674.24	15858826.55	2279674.85	15858826.96	0.61	0.41
M6-8	2262387.71	15863427.62	2262387.74	15863429.78	0.03	2.16
M6-9	2224937.04	15861969.05	2224936.87	15861970.12	-0.17	1.07
M6-10	2214473.16	15817688.46	2214473.86	15817688.76	0.70	0.30
M6-11	2201578.25	15808978.18	2201578.31	15808978.74	0.05	0.56
M6-12	2183377.03	15847072.50	2183377.11	15847072.89	0.08	0.39
M6-13	2220011.38	15842075.00	2220011.10	15842075.44	-0.27	0.44
M12-1	2300471.91	15885309.07	2300472.25	15885309.64	0.34	0.57
Mean ΔX =-0.07 ft Min ΔX =-1.49 ft			Mean ΔY =0.06 ft Min ΔY =-1.24 ft Max ΔY =2.16 ft			

Max ΔX =1.30 ft RMSE ΔX=0.66 ft	RMSE ΔY=0.71 ft
RMSE Ratio=0.93 CE90: 1.48 ft CE95: 1.68 ft	

Table 5 shows the comparison of the coordinates of photo-identifiable points between the orthophotos and the GPS-RTK survey for the 12" (1') GSD data over Minnehaha County. The mean error values are again very small, which indicates that there is no bias in the data. The RMSE indicates that 90% of well defined points have an accuracy of 1.48 ft and 95% of the points have an accuracy of at least 1.68 ft. The error distribution is shown in Figure 6.

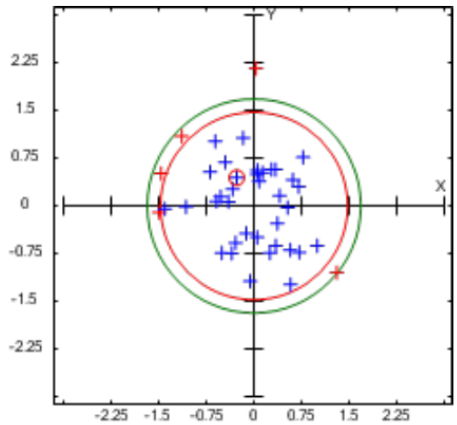


Figure 6: The circular error (CE) plot for Minnehaha County 12" GSD data(from Accuracy Analyst™)

Table 6: Comparison of survey points and photo coordinates over the 12" GSD data over Lincoln County. All measurements are in feet

ID	X(survey, ft)	Y(survey, ft)	X(photo, ft)	Y(photo, ft)	ΔX (ft)	ΔY (ft)
SD10	2207006.81	15784394.42	2207007.69	15784393.09	0.88	-1.33
SD11	2276649.35	15785737.73	2276649.71	15785736.50	0.36	-1.23
SD13	2193499.13	15706655.39	2193498.87	15706654.54	-0.26	-0.85
SD14	2194690.23	15662148.11	2194690.16	15662148.63	-0.07	0.52
SD15	2234356.10	15655090.27	2234356.09	15655091.18	-0.01	0.91
SD16	2313162.96	15667366.07	2313162.91	15667367.31	-0.05	1.24
SD17	2312988.33	15702332.23	2312987.93	15702332.69	-0.40	0.46
SD18	2292260.28	15747111.06	2292261.55	15747110.94	1.28	-0.12
SD19	2272777.50	15691755.41	2272776.91	15691756.16	-0.59	0.75
SD20	2234638.84	15735423.66	2234639.05	15735423.22	0.21	-0.44
SD24	2184079.03	15810046.76	2184078.32	15810047.45	-0.71	0.69
SD26	2249286.19	15780805.75	2249286.03	15780805.21	-0.16	-0.54
SE07	2269473.81	15806741.80	2269474.56	15806741.32	0.75	-0.48
SW05R	2230964.29	15805858.34	2230963.26	15805858.83	-1.02	0.49
L12-1	2265858.58	15764525.86	2265858.22	15764525.89	-0.36	0.03
L12-2	2229058.2	15778369.62	2229057.52	15778368.50	-0.69	-1.12
L12-3	2202194.44	15753125.36	2202193.54	15753125.60	-0.90	0.24
L12-5	2234494.69	15736932.40	2234493.99	15736932.99	-0.70	0.59
L12-6	2234495.19	15736914.59	2234494.02	15736915.00	-1.17	0.41
L12-7	2270443.78	15738133.21	2270443.96	15738133.95	0.18	0.74
Mean ΔX =-0.16 ft Min ΔX =-1.42 ft Max ΔX =1.49 ft RMSE ΔX=0.71 ft			Mean ΔY =-0.09 ft Min ΔY =-1.72 ft Max ΔY =1.24 ft RMSE ΔY=0.79 ft			
RMSE Ratio=0.90 CE90: 1.61 ft CE95: 1.84 ft						

Table 5 shows the comparison of the coordinates of photo-identifiable points between the orthophotos and the GPS-RTK survey for the 12" (1') GSD data over Lincoln County. The mean error values indicate that there may be a small bias of -0.16 ft in the X direction. The circular error values indicate that that 90% of well defined points have an accuracy of 1.61 ft and 95% of the points have an accuracy of at least 1.84 ft. The error distribution is shown in Figure 6.

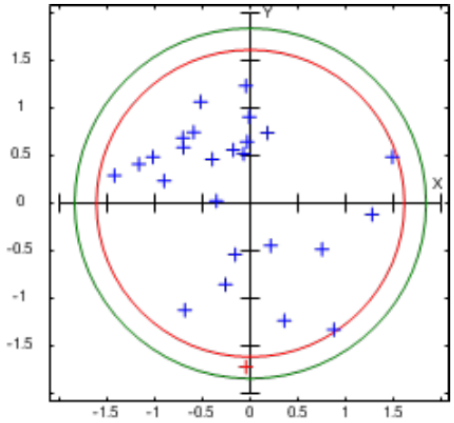
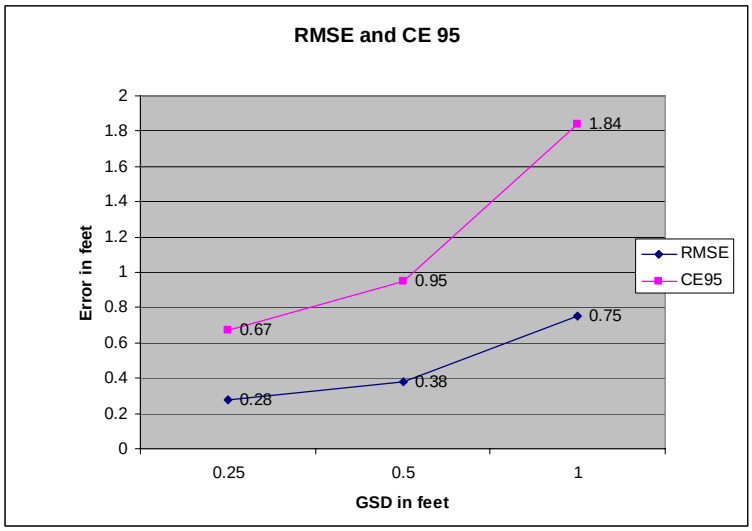


Figure7: The circular error (CE) plot for Lincoln County 12" GSD data (from Accuracy Analyst™)

3 Conclusions

3.1 Summary of the survey

The GPS survey and accuracy assessment revealed that the CE90 and CE95 for the 3”, 6” and 12” data are between 1.6-2 pixels for the corresponding datasets. In terms of ground distances, these come to 0.6 ft for 3” (0.5 ft) GSD data, 0.95 ft for the 6” (0.5 ft) GSD data, and 1.84ft for the 12” GSD (1 ft) GSD data. Figure 8 summarizes the result of the survey versus the orthophotos. The RMSE errors represent the mean errors in the X and the Y directions. The CE 95 errors are slightly more than two pixels for the 3” data, while it is slightly less than 2 pixels for the 6” and the 12” datasets.



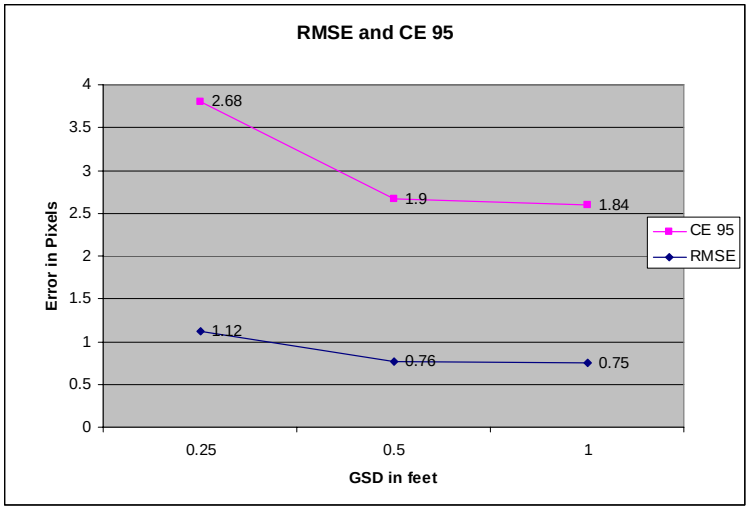


Figure 8: Plot of RMSE and CE 95 errors versus the resolution of the products.

There were some isolated areas where the error was greater than 4 pixels. As shown in Figure9, these areas were located on or near bridges. This could be due to errors in the Digital Elevation Model (DEM) that was used to create the orthophotos. A comparison between the 6” data and the 3” data, which were captured at different times, revealed that they are nearly identical in most areas. However, there are some discrepancies in the data on bridges.

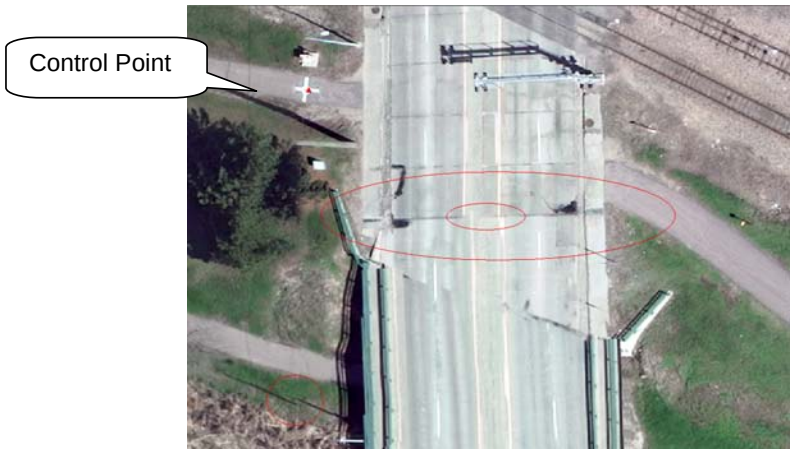


Figure9: Artifacts in the orthophotos.

There is no indication from the three datasets that the errors are dependent on relief, although Sioux Falls and the surrounding areas contain mostly gentle and rolling terrain. It is expected that the data providers meet the accuracy requirements specified by the data procurer, and the CE 95 errors were certainly better than the stated accuracy of 3.3 ft.

Comment [jbc1]: Is this a "stated" accuracy or a "required" accuracy?

4 Recommendations

For future surveys on range validation, it is recommended that the area be divided based on the slope/terrain, urban and rural areas. The National Standards for Spatial Data Accuracy (NSSDA) recommends that for a survey to be statistically meaningful, at least 20 points of a uniform distribution should be measured. Depending on the size of the range, 20 points may or may not be enough. However, 20 points may be enough to give an idea of the spatial distribution of errors. If the points to be surveyed are picked carefully, a pattern of errors (both spatial and contextual) may be established. Further surveys can then be planned, depending on these patterns.

In regions of rapid changes in slope, photo-identifiable points on either side of the slope change should be surveyed. Regions that are flat are likely to be accurate. More generally, the accuracy of the orthophotos depends a great deal on the accuracy of the elevation models available for the area. In this case, Sanborn had generated and used a very accurate LiDAR DEM, which resulted in an accurate ortho product even in areas of high relief. This may not always be the case, and hence photo-identifiable points must be identified more in such areas than in a flat area.

In this dataset, the errors were mostly seen on bridges in urban areas. This can also be because the elevation models for bridges are not reliable.

It is well known that planning any survey can save a lot of time and money. The first step in surveying for range validation is to identify photo-identifiable points that can be surveyed. It is recommended that photo-identifiable points are picked very carefully, keeping the following in mind:

- As far as possible, points must be man-made
- Must be permanent (no areas of ongoing construction)
- Points must be chosen in regions of high contrast
- Points along edges that are strictly N-S or E-W are better picks
- Painted targets are ideal points, but painted lines/road markings are unreliable as they are frequently repainted.
- Points must be picked away from trees/buildings.

The speed and accuracy of the RTK surveying process depends on the availability of accurate control points on which base station receivers can be set up. The base station for the GPS-RTK survey should be placed at the highest point possible. This allows a greater reach for the base station signals, and the surveying process can go much faster. The City of Sioux Falls operates three permanent base station GPS receivers. In the same way, many private surveying companies may operate their own base stations and provide access for a price. The use of such base stations speeds up the process of RTK surveying, and helps keep the costs down.

The use of Google Earth™ or ESRI's ArcGIS™ for optimizing the travel between survey points is recommended. ArcGIS's network analysis module can determine the best/ most optimized route for surveying, once the photo-identifiable points are identified. This can also save a lot of time and money.

References

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Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy (NSSDA): http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3. Last visited: 18th August 2009