1.0 Introduction

Surdex is currently under contract with the St. Louis District of the US Army Corps of Engineers (USACE) to provide precision elevation data deliverables generated from aerial LiDAR data. All data delivered is to meet the USGS LiDAR Base Specification Version 1.0 as defined in August, 2012. This multi-year project consists of several funding partners and requires data inspection and acceptance by the USGS NGTOC.

During the course of producing the 1-meter NPS LiDAR elevation data for the USACE, it was identified by the staff at the USGS NCTOG that an anomaly was visible in some of the 1-meter DEM data produced by Surdex. After several discussions between Surdex and the USACE and the USGS, it was determined that an alternative interpolation scheme for creation of the DEM could reduce this visual anomaly.

2.0 Interpolation Software

The USGS Version 1.0 specification does not define a method for the creation of the DEM data file. Therefore, it is left to each vendor to develop a production methodology that appropriately samples the project LAS files into the desired DEM files. Any commercial and/or custom software can be used to perform this process. As you know, the DEM generation process involves two steps: first a TIN is created by some interpolation method and then an even grid is sampled from the TIN.

The commercial software tools available today have many methods to use in this interpolation which include the following:

i. Nearest neighbor
ii. Inverse Distance Weighting
iii. Spline
iv. Trend
v. Natural Neighbor
vi. Kriging
vii. Binning (average value) from a radius of points
viii. Minimum value from a radius of points
ix. Maximum value from a radius of points

The initial 1-meter DEM data produced under this contract utilized the standard DEM interpolation scheme defined within TerraScan. This algorithm simply utilizes a nearest neighbor methodology to derive an elevation value utilized to form the values for the TIN generation process.

The aerial LiDAR sensors utilized on this project consisted of a Leica ALS70 and an Optech Orion H300 system. Both these sensors utilize an oscillating mirror to scan the ground with the imaging laser. These types of sensor systems can create vibrations that manifest themselves as visible anomalies in the resultant elevation data. In addition, the cell size of the DEM product is essentially the same as the nominal post spacing for the LiDAR dataset (1-meter), so this DEM sample size is going to tend to magnify variations in the dataset especially depending on the sun angle when viewed as a hillshade.

Working from our experience with these sensor systems and DEM interpolation methods, Surdex developed a custom interpolation method that would minimize these visual anomalies in the DEM. This

algorithm utilizes a linear regression model to analytically establish the best points to utilize in the DEM interpolation process. This algorithm was selected to minimize the visual appearance of the anomaly with minimum degradation in the accuracy of the DEM surface. When applied to the Shannon County data, this algorithm produced an esthetically improved DEM data set with an acceptable, nominal degradation in accuracy.

3.0 DEM Review

Figure 1 below presents an area from the original 1-meter DEM data that presented a visual anomaly when displayed in Global Mapper. Figure 2 presents the same area from the 1-meter DEM generated with the Surdex refined DEM interpolation scheme. You can see that the anomaly pattern has been minimized in Figure 2.

Figure 3 presents a cross section profile between the two elevation surfaces. This profile presents the separation that was created by the refined interpolation method, relative to the original DEM surface. You will note that the refined process affected the DEM elevation value by less than 1 cm along this profile.

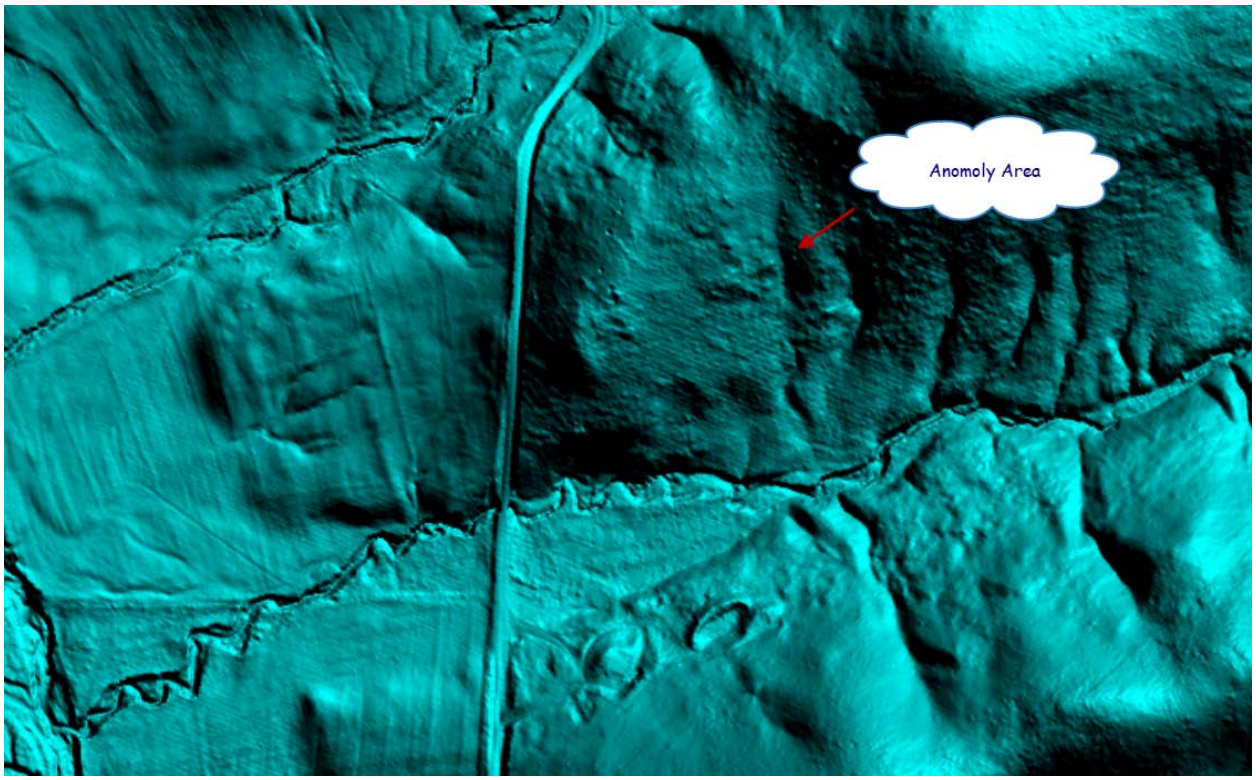

Figure 1: Original 1-meter DEM

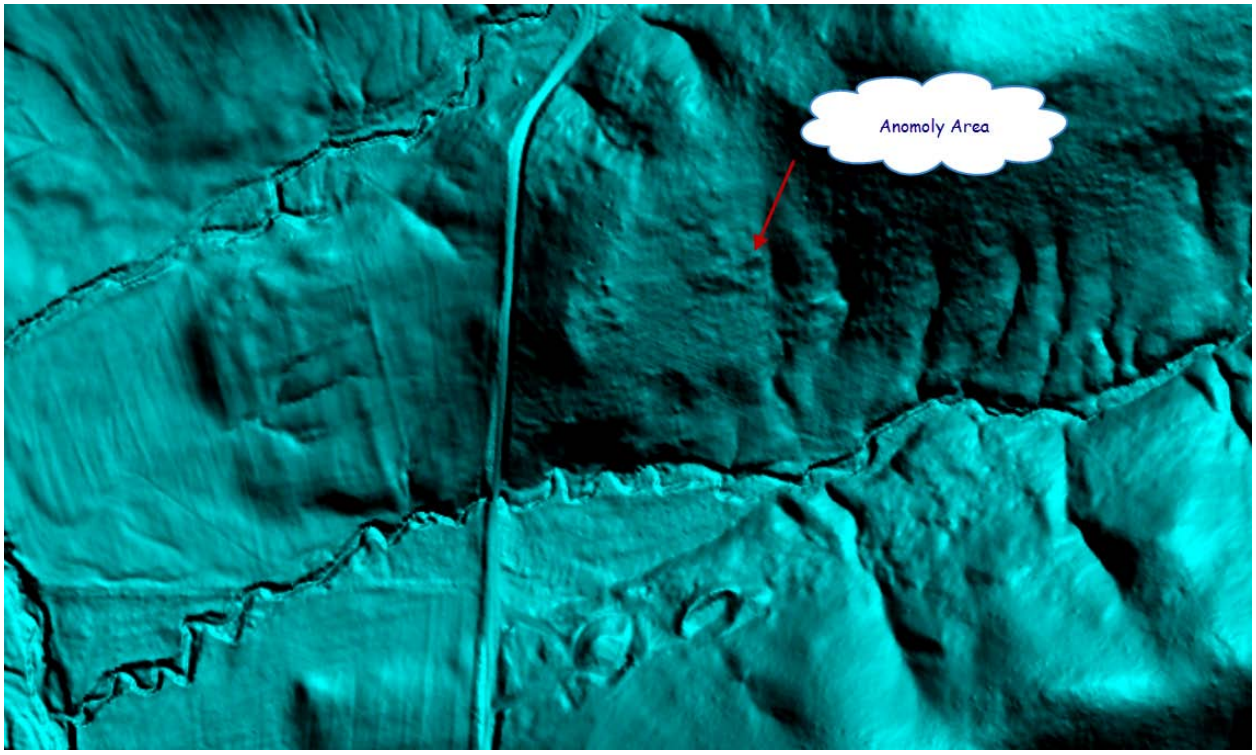

Figure 2: Refined 1-meter DEM with custom interpolation

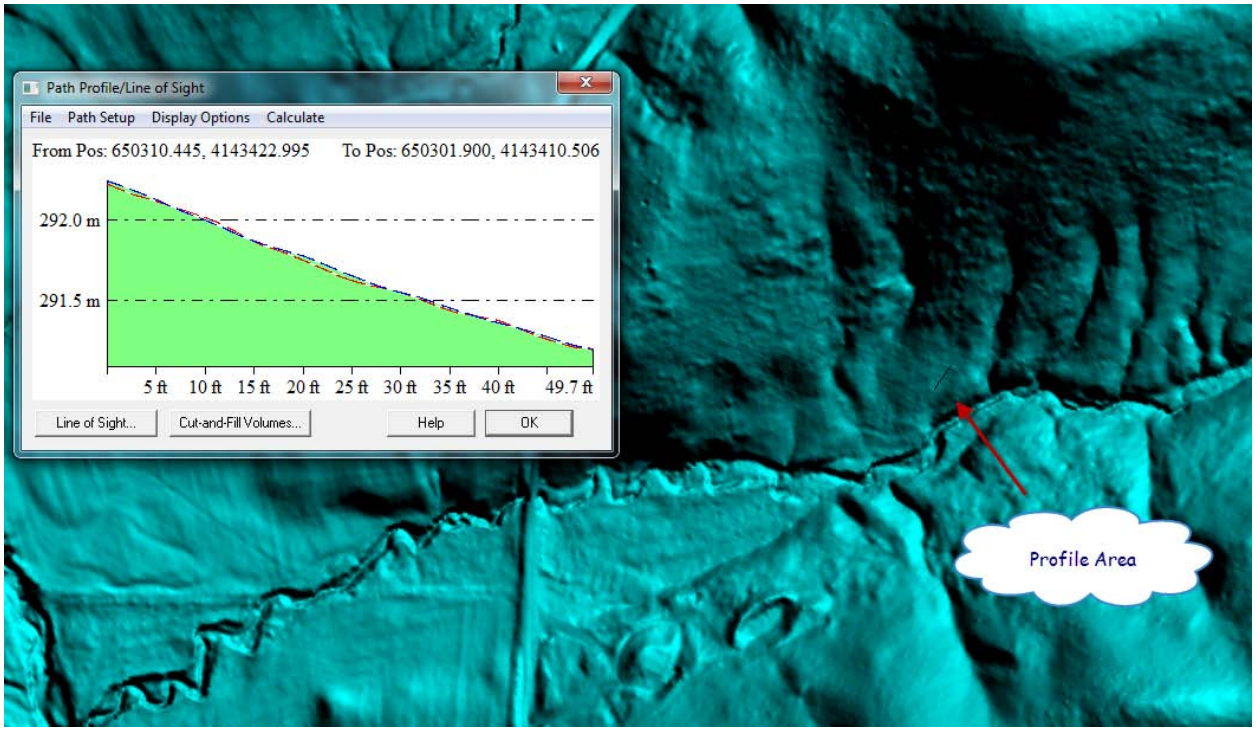

Figure 3: Surface-to-surface comparison between original and refined DEM

4.0 DEM Accuracy

Standard Version 1.0 accuracy testing was performed on the original interpolated DEM files. Table 1 below presents those statistics. A second Version 1.0 DEM accuracy test was performed on the newly interpolated DEM files. These results are provided in Table 2 below. Comparison of these results indicates that the revised interpolation scheme changed the computed DEM RMSE accuracy from 0.097 meters to 0.104 meters for all QC point classes. This reduction in accuracy of 0.007 meters is considered to be minimal when compared against the DEM product accuracy of 0.150 meters absolute.

Table 3 presents a summary of the individual deviations introduced by the new interpolation methodology at each control point location. Review of the last column in the table displays the individual point deviations. A statistical summary of these values indicates that the overall average deviation introduced by the interpolation method is computed to be 0.005 meters relative to the original DEM data files. This minimal change in the DEM accuracy represents the computed effect of the revised interpolation scheme on the DEM product accuracy.

Table 1:
Original 1 Meter DEM Accuracy Assessment

Point ID	Control Easting	Control Northing	Control Elevation	Point Type	LiDAR Surface	Elevation Difference	Hard Surface	Grass	Tree	Absolute
S-1G	649415.012	4153963.902	439.202	grass	439.087	0.115		0.115		0.115
S-4G	651518.699	4142952.763	287.349	grass	287.289	0.060		0.060		0.060
S-5G	646476.510	4139314.654	250.448	grass	250.482	-0.034		-0.034		0.034
S-6G	639704.115	4135940.022	345.317	grass	345.206	0.111		0.111		0.111
S-1HS	649405.413	4153915.997	439.996	HS	439.876	0.120	0.120			0.120
≤20-11HS	645394.979	4131082.735	355.460	HS	355.442	0.018	0.018			0.018
≤20-14HS	638557.894	4131645.677	216.919	HS	216.961	-0.042	-0.042			0.042
≤20-15HS	641479.716	4129836.699	299.580	HS	299.526	0.054	0.054			0.054
S-2HS	656631.730	4151055.918	402.899	HS	402.885	0.014	0.014			0.014
S-3HS	657609.168	4146889.078	405.730	HS	405.723	0.007	0.007			0.007
S-4HS	651527.569	4142963.541	288.712	HS	288.633	0.079	0.079			0.079
S-5HS	646491.400	4139316.006	251.965	HS	251.916	0.049	0.049			0.049
S-6HS	639713.664	4135902.453	346.865	HS	346.716	0.149	0.149			0.149
S-7HS	641478.086	4129827.718	299.187	HS	299.006	0.181	0.181			0.181
S-8HS	640261.406	4132366.251	296.087	HS	296.109	-0.022	-0.022			0.022
S-2T	656616.034	4151071.170	403.054	tree	403.062	-0.008			-0.008	0.008
S-3T	657623.146	4146895.621	408.461	tree	408.542	-0.081			-0.081	0.081
S-4T	651528.969	4142973.133	289.332	tree	289.262	0.070			0.070	0.070
S-5T	646463.893	4139324.943	250.271	tree	250.387	-0.116			-0.116	0.116
S-6T	639739.521	4135926.021	347.032	tree	346.909	0.123			0.123	0.123
S-7T	641457.446	4129834.214	298.284	tree	298.065	0.219			0.219	0.219
S-8T	640270.868	4132391.412	293.849	tree	293.918	-0.069			-0.069	0.069

Summary Statistics

Statistic	ALL	Hard Surface	Grass	Tree
Number of Samples	22.000	11.000	4.000	7.000
Average	0.045	0.055	0.063	0.020
Standard Deviation	0.088	0.071	0.070	0.123
Minimum	-0.116	-0.042	-0.034	-0.116
Maximum	0.219	0.181	0.115	0.219
Sum Squared	0.207	0.084	0.030	0.093
RMSE	0.097	0.087	0.087	0.115
95% CI	0.190	0.171	0.171	0.226
95th Percentile	0.180	0.165	0.115	0.190

Table 2:
Revised 1 Meter DEM Accuracy Assessment

Point ID	Control Easting	Control Northing	Control Elevation	Point Type	LiDAR Surface	Elevation Difference	Hard Surface	Grass	Tree	Absolute
S-1G	649415.012	4153963.902	439.202	grass	439.084	0.118		0.118		0.118
S-4G	651518.699	4142952.763	287.349	grass	287.285	0.064		0.064		0.064
S-5G	646476.510	4139314.654	250.448	grass	250.484	-0.036		-0.036		0.036
S-6G	639704.115	4135940.022	345.317	grass	345.224	0.093		0.093		0.093
S-1HS	649405.413	4153915.997	439.996	HS	439.846	0.150	0.150			0.150
s20-11HS	645394.979	4131082.735	355.460	HS	355.439	0.021	0.021			0.021
s20-14HS	638557.894	4131645.677	216.919	HS	216.959	-0.040	-0.040			0.040
s20-15HS	641479.716	4129836.699	299.580	HS	299.524	0.056	0.056			0.056
S-2HS	656631.730	4151055.918	402.899	HS	402.881	0.018	0.018			0.018
S-3HS	657609.168	4146889.078	405.730	HS	405.720	0.010	0.010			0.010
S-4HS	651527.569	4142963.541	288.712	HS	288.625	0.087	0.087			0.087
S-5HS	646491.400	4139316.006	251.965	HS	251.881	0.084	0.084			0.084
S-6HS	639713.664	4135902.453	346.865	HS	346.711	0.154	0.154			0.154
S-7HS	641478.086	4129827.718	299.187	HS	299.007	0.180	0.180			0.180
S-8HS	640261.406	4132366.251	296.087	HS	296.102	-0.015	-0.015			0.015
S-2T	656616.034	4151071.170	403.054	tree	403.052	0.002			0.002	0.002
S-3T	657623.146	4146895.621	408.461	tree	408.542	-0.081			-0.081	0.081
S-4T	651528.969	4142973.133	289.332	tree	289.193	0.139			0.139	0.139
S-5T	646463.893	4139324.943	250.271	tree	250.397	-0.126			-0.126	0.126
S-6T	639739.521	4135926.021	347.032	tree	346.919	0.113			0.113	0.113
S-7T	641457.446	4129834.214	298.284	tree	298.072	0.212			0.212	0.212
S-8T	640270.868	4132391.412	293.849	tree	293.947	-0.098			-0.098	0.098

Statistics	ALL	Hard Surface	Grass	Tree
Number of Samples	22.000	11.000	4.000	7.000
Average	0.050	0.064	0.060	0.023
Standard Deviation	0.093	0.073	0.068	0.133
Minimum	-0.126	-0.040	-0.036	-0.126
Maximum	0.212	0.180	0.118	0.212
Sum Squared	0.236	0.099	0.028	0.109
RMSE	0.104	0.095	0.084	0.125
95% CI	0.203	0.186	0.164	0.245
95th Percentile	0.179	0.167	0.114	0.190

Table 3:
Revised 1 Meter DEM Accuracy Assessment Comparison

Point ID	Control Easting	Control Northing	Control Elevation	Point Type	LiDAR Surface	Elevation Difference	Hard Surface	Grass	Tree	Absolute	Original DEM Elevation Difference	Change In Elevation From Interpolation
S-1G	649415.012	4153963.902	439.202	grass	439.084	0.118		0.118		0.118	0.115	-0.003
S-4G	651518.699	4142952.763	287.349	grass	287.285	0.064		0.064		0.064	0.060	-0.004
S-5G	646476.510	4139314.654	250.448	grass	250.484	-0.036		-0.036		0.036	-0.034	0.002
S-6G	639704.115	4135940.022	345.317	grass	345.224	0.093		0.093		0.093	0.111	0.018
S-1HS	649405.413	4153915.997	439.996	HS	439.846	0.150	0.150			0.150	0.120	-0.030
s20-11HS	645394.979	4131082.735	355.460	HS	355.439	0.021	0.021			0.021	0.018	-0.003
s20-14HS	638557.894	4131645.677	216.919	HS	216.959	-0.040	-0.040			0.040	-0.042	-0.003
s20-15HS	641479.716	4129836.699	299.580	HS	299.524	0.056	0.056			0.056	0.054	-0.002
S-2HS	656631.730	4151055.918	402.899	HS	402.881	0.018	0.018			0.018	0.014	-0.004
S-3HS	657609.168	4146889.078	405.730	HS	405.720	0.010	0.010			0.010	0.007	-0.003
S-4HS	651527.569	4142963.541	288.712	HS	288.625	0.087	0.087			0.087	0.079	-0.008
S-5HS	646491.400	4139316.006	251.965	HS	251.881	0.084	0.084			0.084	0.049	-0.035
S-6HS	639713.664	4135902.453	346.865	HS	346.711	0.154	0.154			0.154	0.149	-0.005
S-7HS	641478.086	4129827.718	299.187	HS	299.007	0.180	0.180			0.180	0.181	0.002
S-8HS	640261.406	4132366.251	296.087	HS	296.102	-0.015	-0.015			0.015	-0.022	-0.007
S-2T	656616.034	4151071.170	403.054	tree	403.052	0.002			0.002	0.002	-0.008	-0.010
S-3T	657623.146	4146895.621	408.461	tree	408.542	-0.081			-0.081	0.081	-0.081	0.000
S-4T	651528.969	4142973.133	289.332	tree	289.193	0.139			0.139	0.139	0.070	-0.069
S-5T	646463.893	4139324.943	250.271	tree	250.397	-0.126			-0.126	0.126	-0.116	0.009
S-6T	639739.521	4135926.021	347.032	tree	346.919	0.113			0.113	0.113	0.123	0.010
S-7T	641457.446	4129834.214	298.284	tree	298.072	0.212			0.212	0.212	0.219	0.007
S-8T	640270.868	4132391.412	293.849	tree	293.947	-0.098			-0.098	0.098	-0.069	0.029

Statistics	ALL	Hard Surface	Grass	Tree
Number of Samples	22.000	11.000	4.000	7.000
Average	0.050	0.064	0.060	0.023
Standard Deviation	0.093	0.073	0.068	0.133
Minimum	-0.126	-0.040	-0.036	-0.126
Maximum	0.212	0.180	0.118	0.212
Sum Squared	0.236	0.099	0.028	0.109
RMSE	0.104	0.095	0.084	0.125
95% CI	0.203	0.186	0.164	0.245
95th Percentile	0.179	0.167	0.114	0.190

5.0 Summary

This paper has been assembled to present a refined interpolation scheme developed by Surdex to minimize visual anomalies present in some aerial LiDAR 1-meter DEM data being produced for the USACE and reviewed by the USGS. This paper summarizes the effect of this refined interpolation algorithm on the resultant DEM and a summation of the overall accuracy impact. Based upon these findings it is apparent that this interpolation methodology will improve the visual appearance of the 1-meter DEM with minimal impact on the final product accuracy. The final Shannon County 1-meter DEM files meet the project accuracy specifications.

Sincerely,

Steven M. Kasten

Steven M. Kasten CP, PLS, PSM