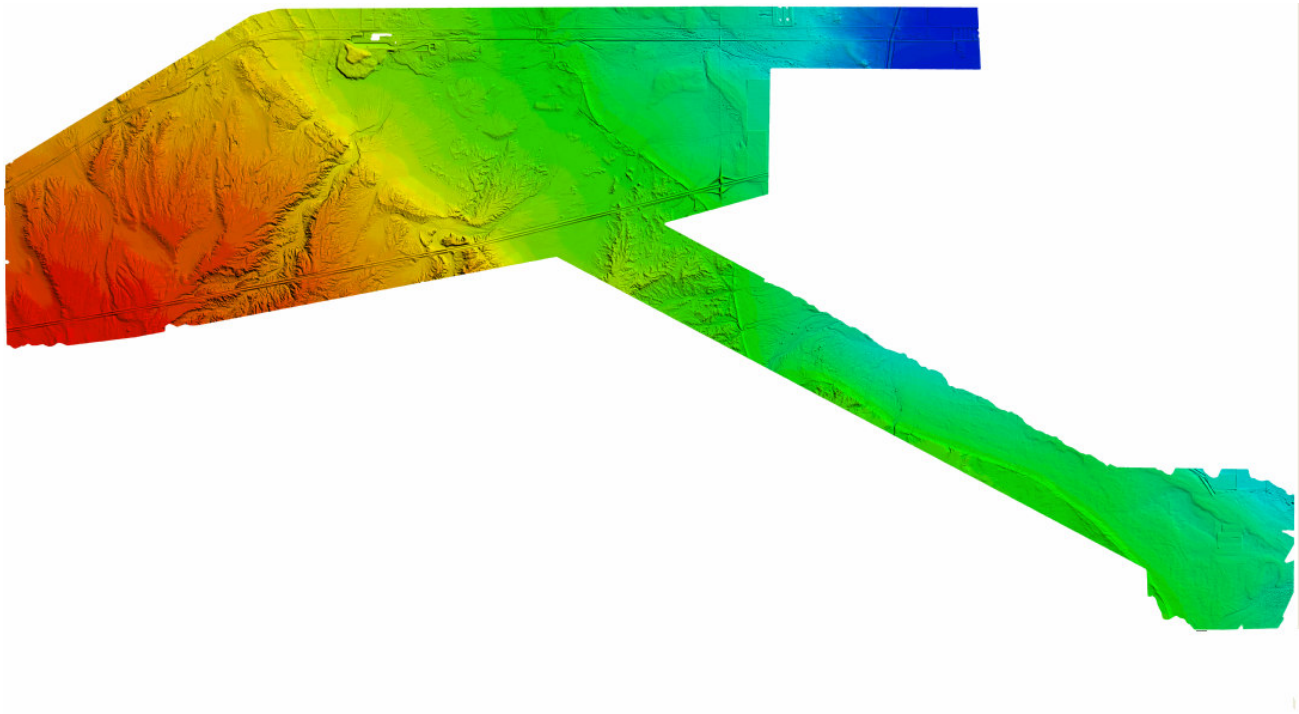
Appendix G
Topo Survey Report



Aerial Topographic Mapping
Solar 2 and Related Sites
Final Project Report

Imperial County, California
Report Date: 15 April 2008

Table of Contents

I. INTRODUCTION.....1

II. GROUND SURVEY 1

III. LIDAR 1

IV. AERIAL PHOTOGRAPHY.....2

V. MAP COMPILATION 2

VI. QA/QC.....2

VII. DELIVERY 2

Appendix A: LIDAR US Operational Procedures 3-14

Aerial Topographic Mapping
Solar 2 and Related Sites
Final Project Report

Imperial County, California
Report Date: 15 April 2008

I. INTRODUCTION

Stantec completed aerial topographic mapping and ortho-photo production for Solar 2 and related sites in March of 2008. The final deliverables were distributed via FTP and DVD; they included: AutoCAD-format topographic line maps, AutoCAD-format digital terrain models (DTM's), and tif-format ortho-photographs. The project followed these steps:

- Review of Project specifications and development of QA/QC system
- Planning: Photo and control layout
- Ground Survey: Set and position aerial targets
- Remote Sensing: Collection of LiDAR data and aerial photographs
- Data Processing: Ground survey GPS processing, Aero-Triangulation
- Map Compilation
- Final QA/QC: Comparison of ground-survey data to final mapping products
- Delivery

II. GROUND SURVEY

Stantec set 42 aerial targets covering Solar 2, the proposed water-line, and the proposed transmission line and sub-station. The targets were positioned in a static GPS control network, with local continuously operating reference stations (CORS) and NGS NAVD88 bench marks held as horizontal and vertical controls. GPS vectors were processed with Trimble Geomatics Office v1.63, and final coordinates and elevations were calculated in a least-squares adjustment in StarPlus Star*Net v6.0.

Field crews operated a GPS Base-station which collected carrier-phase GPS data while the aircraft captured Lidar data and photographs. The airborne GPS data was used to post-process the LiDAR data.

Additional field data was collected to determine the West-Side Canal water level and pump station locations.

Field crews returned to the site after the aerial photographs were accepted in order to remove all aerial targets from BLM and private lands.

III. LIDAR

Light Detection and Ranging (LiDAR) data was obtained using an airborne sensor mounted on an aircraft. Periodic pulses were emitted and received and the time delay between them resulted in a calculation of the terrain elevation at that given location. Multiple passes of the area were made to cover the entire project site. The data was delivered in ASCII file format and imported into the mapping software. The resulting data was sufficient to produce 2' contours.

Information on the calibration, corrections, and results of the LIDAR data collection are included in APPENDIX A: LIDAR US Operational Proceures.

IV. AERIAL PHOTOGRAPHY

New color aerial photography was obtained of the project site at a scale of 1”=600’. Individual negative frames were then scanned and processed to be used for the mapping.

V. MAP COMPILATION

All mapping efforts for this project utilized KLT/Atlas mapping software. An aero-triangulation solution was calculated using the aerial targets and manually recorded photogrammetric pass points. The solution was examined to ensure that National Map Accuracy Standard horizontal and vertical accuracies were met for the 1”=100’ map scale and 2’ contour interval of this project. A digital terrain model was developed using both photogrammetric breaklines and the LiDAR elevation data. Two foot contours were generated and added to the planimetric features that were complied. Mapping files were then translated into AutoCAD, edited and reviewed for completeness.

VI. QA/QC

Stantec crews collected approximately 500 random elevation measurements across the site using post-processed kinematic (PPK) GPS techniques. The “check-points” were compared to the elevations on the topographic maps using an automated program, Topo Check. In all areas of the site, the map elevations agreed with the ground-survey elevations within ½ of a contour interval (1 Foot).

VII. DELIVERY

Final mapping files were delivered in AutoCAD version 2008 and followed a tiled format of quarter-township sections, or an overall composite drawing file. Color TIFF format orthophotos, each with a pixel resolution of 0.5’ were delivered following the same tile system.

APPENDIX A:

OPERATIONAL PROCEDURES

December 2007

El Centro Project

Introduction

The purpose of this report is to explain the procedures that LIDAR US Inc. takes to calibrate its proprietary LIDAR system, ensuring the highest quality data possible. Explanations will be given on how the lever arms were measured, our calibration procedures, quality control procedures and the system's specifications. It should be noted that any values, measurements or positions are for procedure demonstration and not the information used in any specific installation or project.

Lever Arm Measurements

Three main measuring devices are used in our system: a GPS receiver, an Inertial Measurement Unit (IMU) and a laser range finder. The post-processed GPS positions of the aircraft are always calculated at the location of the GPS antenna, but we are interested in positioning the laser head because it is from there that the distances toward the ground are measured. Therefore, the coordinates have to be transferred from the GPS antenna to the laser head. The precise position and attitude of the laser is determined through a post-processed Kalman filtered solution, blending the data from the IMU's gyros and accelerometers with the GPS positions. Lever arms must be measured from the receiving head of our scanning laser to the GPS antenna, as well as from the laser to the IMU in order to calculate the laser positions.

All measurements are referenced from the laser plane (not the aircraft plane) to the other two sensors. It follows the right hand rule with the positive value of the X-axis pointing toward the nose of the aircraft, the Y-axis toward the right wing and the Z-axis pointing down.

Procedures

The aircraft is parked in a hanger or suitable flat surface and the inclination of the sensor platform was measured with a digital level, giving an angle of 7.7 degrees from the ground. A surveyor's plum bob and a measuring tape were used to calculate the offsets. Since not all distances could practically be measured (for example: right to the laser head or at a perfect right angle), sufficient measurements were taken to derive the resulting offsets by subtractions and simple trigonometry. In the following examples a helicopter is used but the procedure is identical with any aircraft.

Values

The resulting lever arms for Laser to GPS antenna and Laser to IMU are:

VIII. LASER → GPS ANTENNA	LASER → IMU
DX = -2.557 m	**DX = -0.025 m**
DY = +0.194 m	**DY = +0.413 m**
DZ = -1.764 m	**DZ = +0.002 m**

Figure 1 - shows a front view of the measurements to derive the GPS antenna DX and DZ lever arms.
Figure 2 - shows a top view of the measurements for the GPS antenna DY lever arms.
Figure 3 - shows a top and front view of the IMU lever arms.

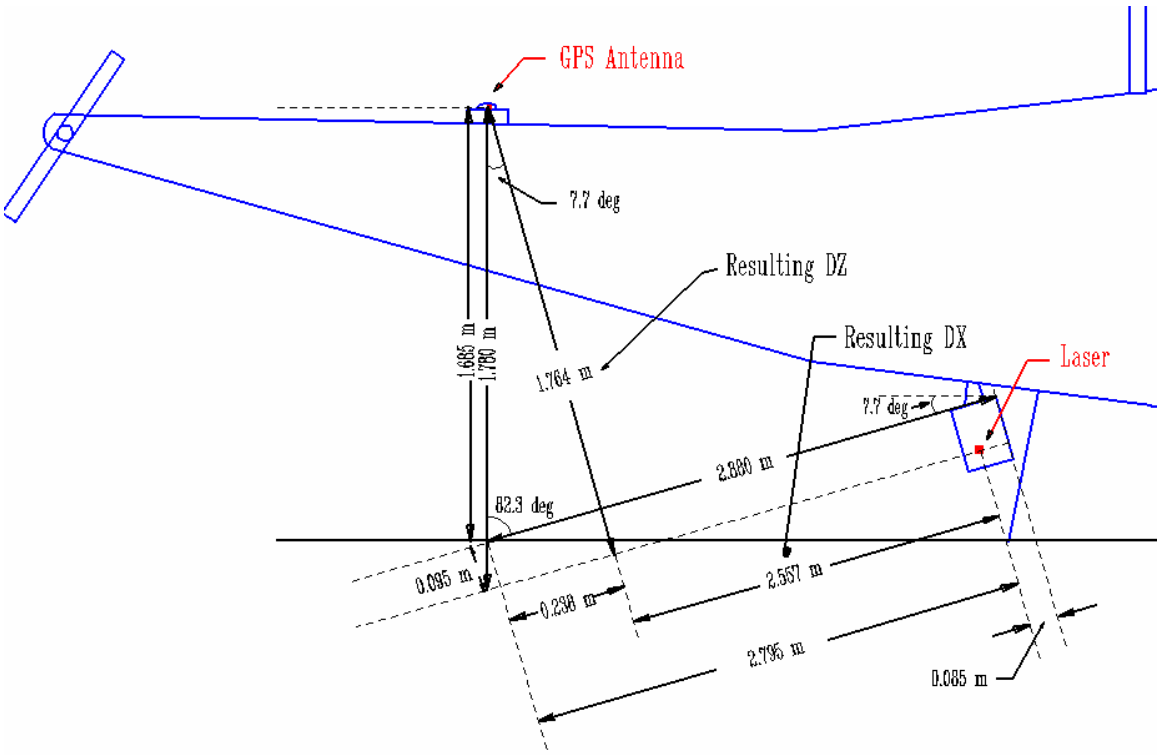


Figure 1 - DX and DZ lever arms for the GPS antenna (front view)

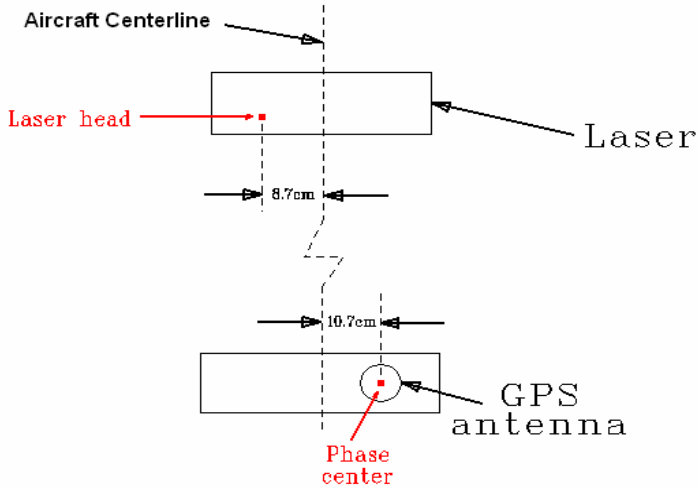


Figure 2 - DY lever arm for the GPS antenna, DY = +0.194 m (top view)

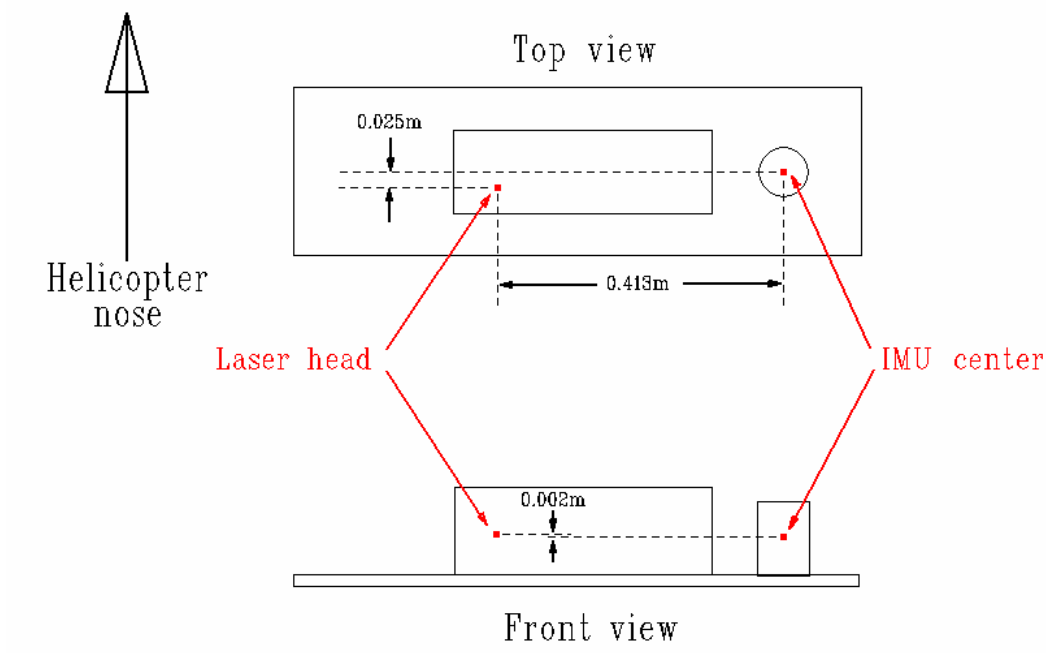


Figure 3 – Lever arms for the IMU

Calibration

Since the attitude information coming from the orientation software is for the IMU itself, the angles between the IMU and the Laser must be determined in order to accurately measure the ground. These angles must be determined accurately to meet our specifications, and the way we determine them is by using the LiDAR data over an area with a variety of features such as large buildings, power lines, lakes and rivers. The system is typically relatively calibrated, that is the relative positions of a building or feature are used and those calibration values used to compare the LiDAR data to a surveyed area. This method is based on trial and error, and measuring the distance between identifiable features from different scan swaths.

Heading (Yaw) offset

Knowing the approximate pitch and roll offset angles between the two instruments (which are installed to be near zero), the first step is to determine the heading (or yaw) offset. The method we use is as follows: we fly parallel lines at high altitude, from different directions, with some overlap over a well-defined river or large building or buildings. The laser does not reflect over water, therefore leaving a blank trail where the water is. From a top view of the laser returns we can visually see if the adjacent swaths line up. By trial and error, we adjust the heading offset until the outside edges line up. It is possible to measure the distance between the river edges from adjacent swaths, and the heading offset is determined acceptable when the distance meets our horizontal specifications. The same technique is used with buildings with the outside edges of the swath used to line up the building edge.

Figure 4 below shows the laser swaths not lining up and Figure 5 shows the river lining up after the proper heading offset has been applied.

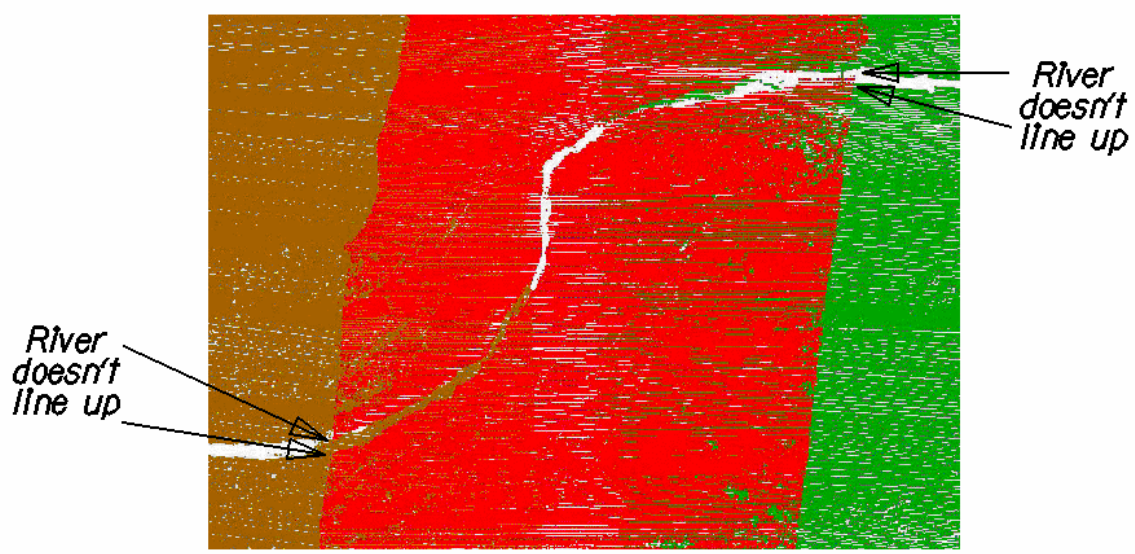


Figure 4 – Laser swaths not lining up (wrong heading offset)

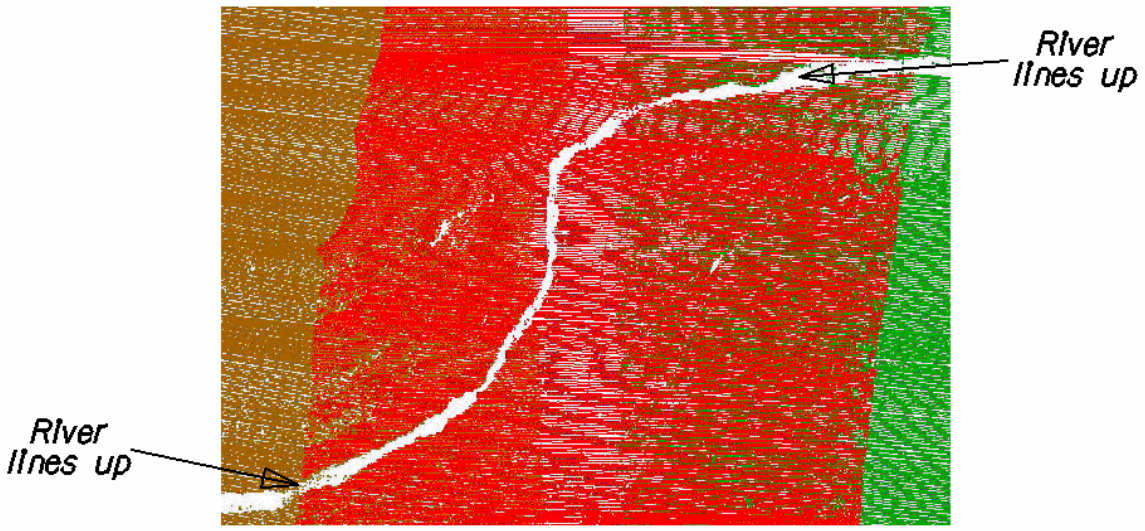


Figure 5 – Laser swaths lining up (proper heading offset)

Pitch and Roll Offsets

Once the heading offset has been calculated, the pitch and roll offsets can be determined. The LiDAR data is acquired on a large building from opposite directions and offset or misalignment can be visually displayed. Again, by trial and error, we adjust the pitch and roll offsets until the walls and building edges line up. It is possible to measure the distance between the building edges from opposite swaths, and the offsets are determined acceptable when the distance meets our horizontal and vertical specifications.

Roll

The roll offset is easier to determine by looking at how a wall vertically lines up from a side view.

Figure 6 below shows the laser returns on the building with a one-degree roll offset error. Figure 7 shows the buildings lining up after the proper roll offset has been applied.

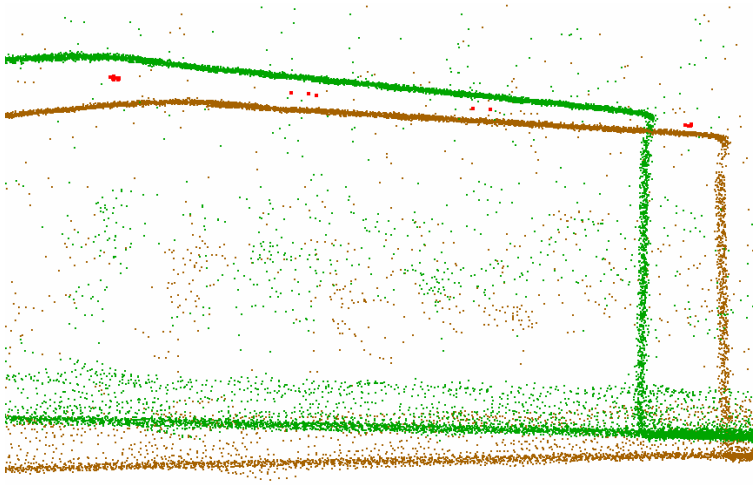


Figure 6 – Side view of two laser swaths with a one-degree roll offset error.

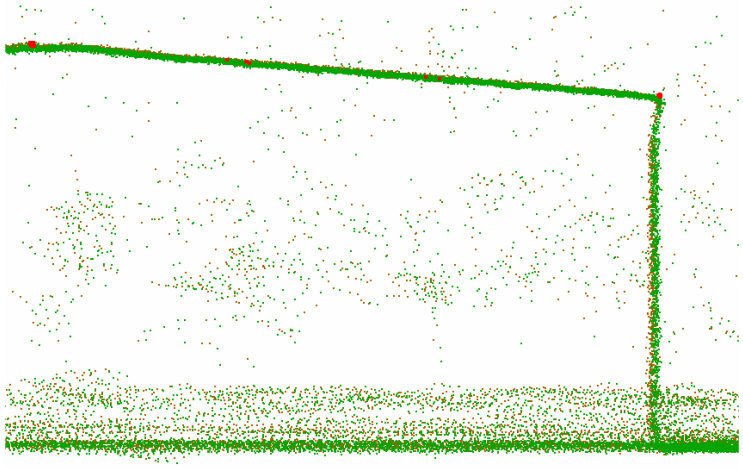


Figure 7 – Side view of two laser swaths with the proper roll offset.

Pitch

The pitch offset is determined by looking at how the building edges line up from a top view. Figure 8 below shows the laser returns not lining up with the building edges.
Figure 9 shows the buildings lining up after the proper pitch offset has been applied.

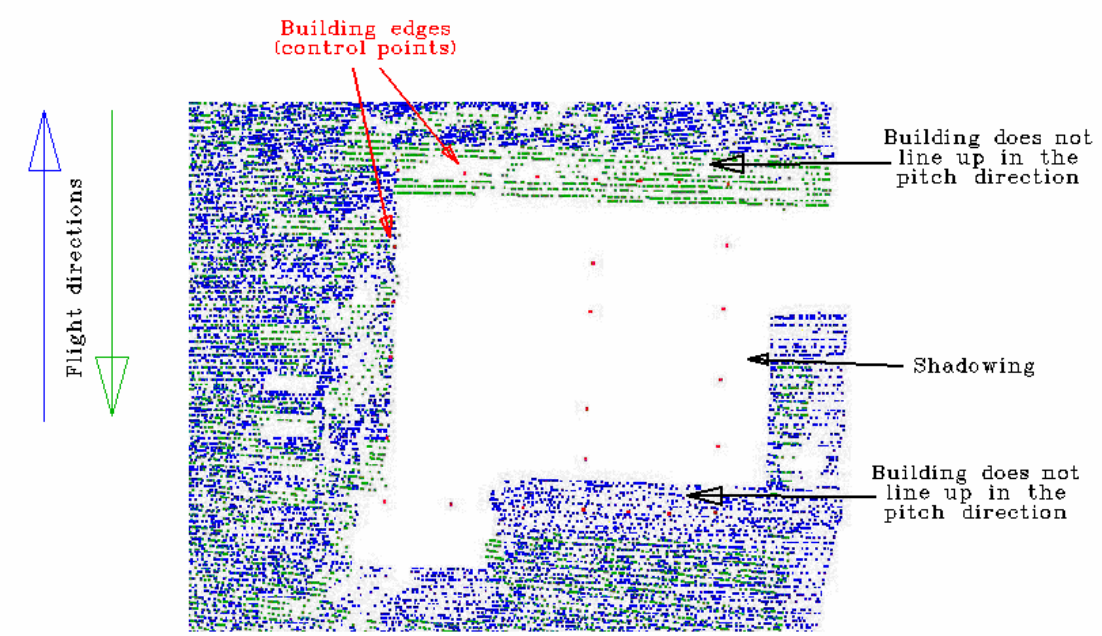


Figure 8 – Top view of two laser swaths with a one-degree pitch offset error.

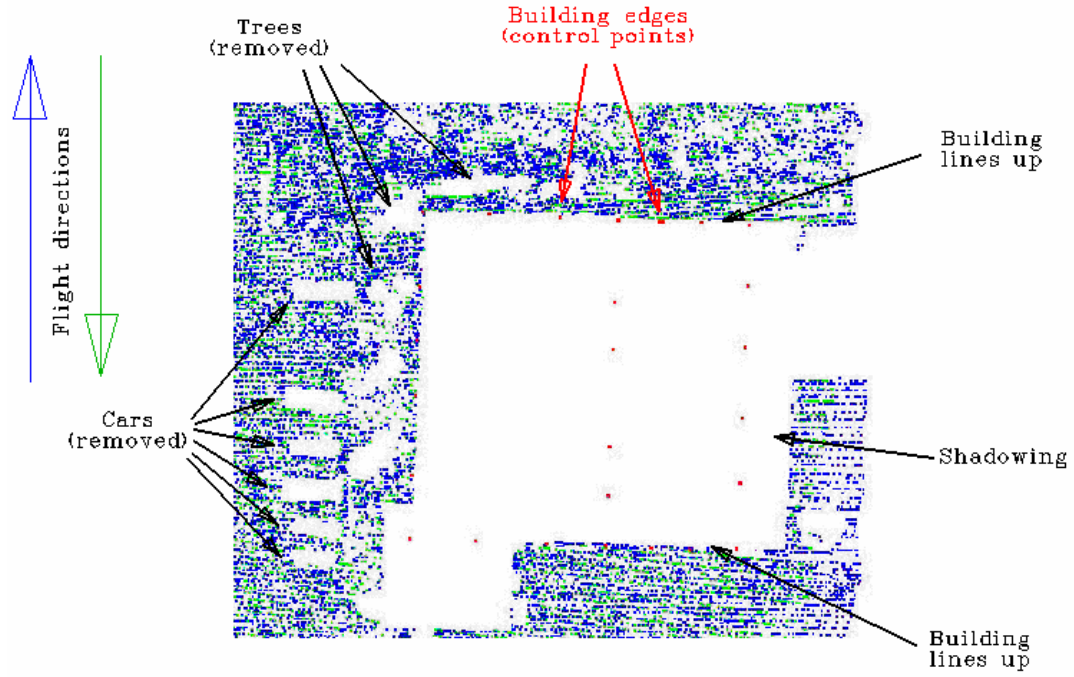


Figure 9 – Top view of two laser swaths with the proper pitch offset.

Offset Values

The present offset angles for the October, 2007 installation are:

Pitch: +0.110 degree
Roll: +0.140 degree
Heading: +0.001 degree

This calibration is done periodically, and every time the system's components are manipulated or un-installed.

Quality Control

Static Control Survey

A geodetic network is generally established in the area to provide the basis for the positioning the LiDAR survey. Typically existing survey control markers from the National Geodetic Survey are utilized and new control established where required for the purpose of reducing the base line distance to the aircraft to less than 30 kilometers. The static data is processed using Waypoint GrafNet software to produce a least squares adjustment holding the most accurate points fixed. http://www.novatel.com/products/waypoint_grafnav.htm
In addition wherever possible CORS data is also utilized and independently processed using the on-line OPUS solution. http://www.ngs.noaa.gov/OPUS/What_is_OPUS.html

Kinematic survey

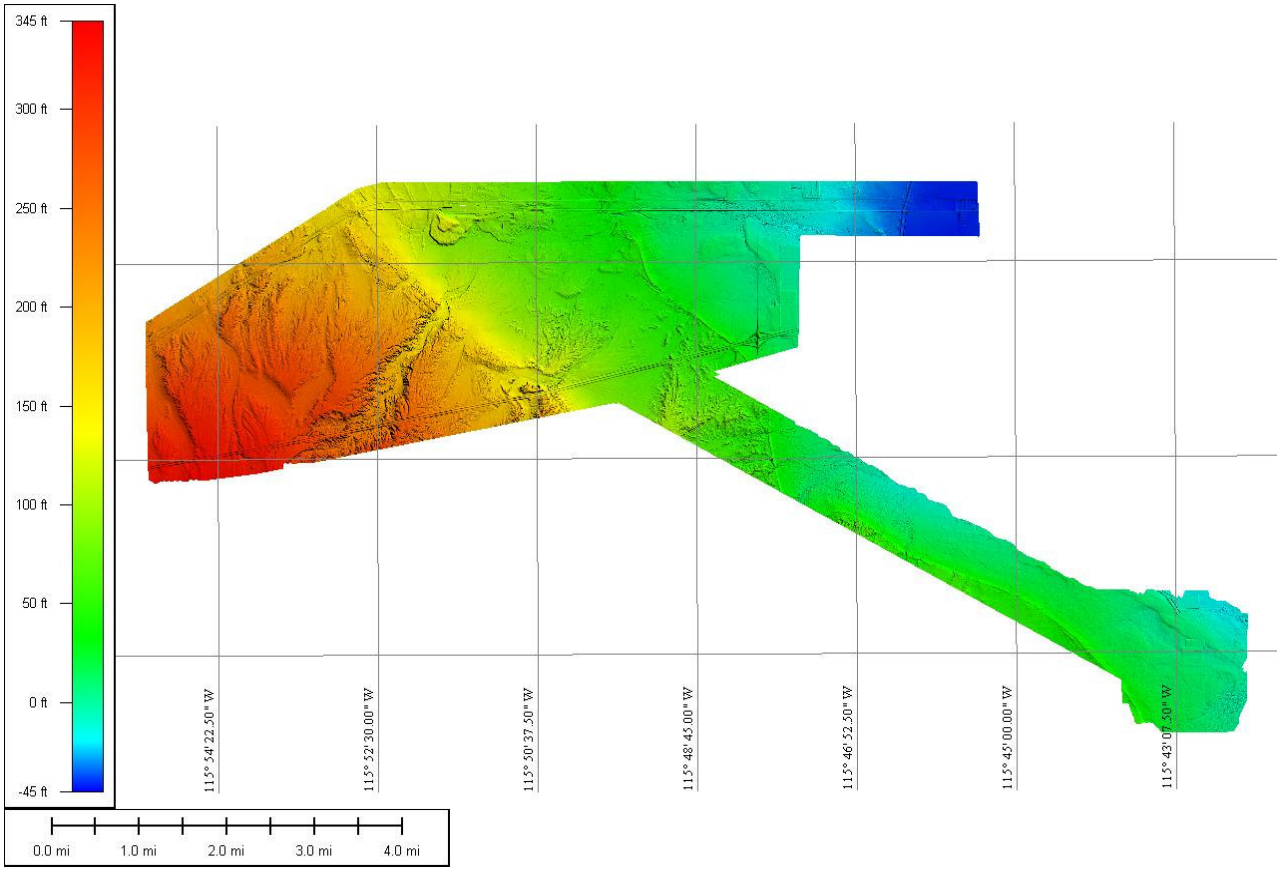
On every LiDAR project flown, LIDAR US Inc. performs its own quality control by surveying control points covering the area. A convenient method is to do a GPS kinematic survey to provide a qualitative and quantitative assessment of the LiDAR accuracies. A mobile, truck mounted, GPS unit, and a stationary base station, collects simultaneous raw data at typically 0.5 second intervals for post processing. Roads, trails and open areas in the project area are driven yielding thousands of high quality points for comparison purposes. The data is post processed using Waypoint Grafnav software http://www.novatel.com/products/waypoint_pps.htm. Only points with reliable fixed integer solutions are kept and used as control points to compare with the LiDAR results. We estimate that the accuracy of these control points is in the order of 5 centimeters.

Statistical analysis

Once the LiDAR data has been processed, only ground points are kept, removing all vegetation and man-made structures from the data set. The ground hits are then usually thinned, removing points that had an elevation difference of less than 5 cm compared to the other points within a 1-meters radius, keeping the lowest points. This thinning method allows us to keep more points in steeper terrain and remove unnecessary points in flat areas, which results, with these parameters, in about half the number of points without losing any ground definition. From these ground points, a Triangulated Interpolation Network is created. An evenly spaced grid can be interpolated from all the ground points, depending on client specification.

The elevations of the kinematic ground points are then compared to the elevations from the DTM . The worst 5% of the kinematic points are discarded. The elevations of the kinematic ground points are then re-compared to the elevations from the DTM.

Project Specific Information



El Centro LiDAR Project

DESCRIPTION=<ELCENTRO_SP_LiDAR Dataset>
UPPER LEFT X=6662843.67
UPPER LEFT Y=1869014.61
LOWER RIGHT X=6729493.67
LOWER RIGHT Y=1837034.61
WEST LONGITUDE=115° 55' 15.95" W
NORTH LATITUDE=32° 47' 40.19" N
EAST LONGITUDE=115° 42' 14.01" W
SOUTH LATITUDE=32° 42' 21.00" N
MIN ELEVATION=-45.1 feet
MAX ELEVATION=344.7 feet
ELEVATION UNITS=feet

El Centro Project- LiDAR Acquisition Parameters

System – DWM ALIS-560 mounted on Cessna 210 Aircraft

Flight Line Spacing	**250m**
AGL	**500m**
Overlap	**56%**
Laser Max PRR	**200Khz**
Sample rate	**133Khz**
Average coverage	**8-10 points per sq. meter**