LIDAR Report

Las Cabras

1. Project Overview and History

GPPA, S.C. was contracted to perform a LiDAR survey located near Mazatlan, Sinaloa Mexico. The acquisition was completed November 2, 2009. The survey consisted of approximately 50 square kilometres of coverage.

This report describes the acquisition, post-processing and quality control methodology used to produce the final elevation models.

2. GPS Control

Upon arriving in Mazatlan on Oct 30, 2009 our team started the installation of the LiDAR system and ground GPS survey. Our survey team performed a field review of the established local INEGI geodetic control to be used as possible ABGPS base stations at the Mazatlan International airport and on the project site.

Our survey team was not able to locate and recover any INEGI established ground survey control so we established a temporary survey point at the airport called Air1 and one at the project site called ESC1. Air1, the survey point located at the airport was occupied for (3) three days and tied to INEGI Cors stations located in La Paz, Colima and the primary INEGI CORS station located in Aguascalientes.

ABGPS Base Station located at the Mazatlan International Airport – "Air 1"

ABGPS located at the project site – ESC1

Static GPS baselines were observed over three (3) days, jd304, jd305, jd 306 for Air1 and jd306 for ESC1 to determine the final values for AIR1 (ABGPS base station) and or back up ABGPS base station ESC1.

We performed 3- d constrained network adjustments constraining (holding)the to three (3) INEGI continuous operating reference stations located in LA PAZ (LPAZ), Colima (Col2) and INEGI located in Aguascalientes. The actual GPS data was downloaded for the INEGI CORs stations from the United States National Geodetic Survey web site. All three continuous operating stations are high accuracy and have an internal accuracy of 2cm.

<u>CORS Station Values:</u>

LAPAZ (INEGI)
Latitude: 24 08 33.17336 (N)
Longitude: 110 58 01.96439 (W)
Ellipsoid Elevation: -6.785meters

COL2 (INEGI)
Latitude: 19 14 39.99621 (N)
Longitude: 103 42 06.77421(W)
Ellipsoid Elevation: 528.837 meters

INEGI (INEGI)
Latitude: 21 51 22.15474 (N)
Longitude: 102 17 03.12524(W)
Ellipsoid Elevation: 1888.09 meters

Final Results

Air1	LATITUDE	LONGITUDE	ELLHGT	ORTHOHGT
jd304	23 09 59.98919	-106 15 56.20770	-17.5709	7.5144
jd305	23 09 59.98970	-106 15 56.20718	-17.4447	7.6406
jd306	23 09 59.98997	-106 15 56.20707	-17.4569	7.6285
Average	**23 09 59.98962**	**106 15 56.20732**	**-17.4908**	**7.5945**

Esc1	LATITUDE	LONGITUDE	ELLHGT	ORTHOHGT
Cors	22 44 51.60427	-105 51 39.27035	-20.681	4.0322
Air1	22 44 51.60390	-105 51 39.27027	-20.722	3.9912
Average	**22 44 51.60407**	**105 51 39.27031**	**-20.702**	**4.0117**

The final position and ellipsoid elevations were determined by averaging each computed day positions and ellipsoid elevations.

3. ABGPS Base Station and Processing

Prior to the LiDAR data acquisition, ABGPS base stations were set up on Air1 (Primary base station) and our back up ABGPS base station 9ESC1). Airborne GPS processing was completed using **Air1.**

ABGPS processing and acceptance criteria

- Data processed using Waypoint Software's "Grafnav" Kinematic processing module. Both a forward and reverse solution was processed and the separation of these solutions was used as acceptance criteria. Acceptable criteria was **10cm RMS and quality one (1) solution** in a combined forward/reverse solution
- Ellipsoid model used was WGS84
- Geoid model used was Mexico97 to produce orthometric elevations

LiDAR System and Aircraft

The project was flown using our high altitude Reigl 560 LiDAR system and Cessna 182 aircraft.

4. Calibration Calibration

The calibration of ALIS-80S LiDAR system is performed periodically and normally at the onset and conclusion of each project. There are two main purposes in calibrating the system. First is to measure the lever arms between our three main sensors (Laser, GPS antenna and IMU). This can be done on the ground by physically measuring distances with a measuring tape along the three axes obtained from a digital level. Second is the measurement of the small angle differences in the way the Inertial Measurement Unit and the Laser are mounted (roll, pitch and heading). This is much harder to do because the angles have to be measured to 0.05-degree accuracy or better. If it is not achieved, errors will be magnified on the ground when flying at higher elevations. Our approach to measuring these angles is to measure the displacement on the ground of the un-calibrated system, and iteratively feed in the offset until the best alignment is achieved.

Please refer to Calibration Report (Oct 31 2009) in Appendix A for detailed explanations on the methodology.

Calibration flights were done on Oct 31,2009 over an area near the City of Mazatlan. Multiple passes were flown over a large building to determine horizontal calibration and a large open area to verify our vertical accuracy.

The calibration values can be found in the October 31, 2009 Calibration report.

4. LIDAR Acquisition

Our acquisition team utilized the following parameters:

Estimated Flight Altitude:	450m above mean terrain
Estimated Average Ground Speed:	110 mph, 50m/s or 97 Knots
Estimated Distance between flight lines:	250 meters
Estimated Flight Line Overlap:	270 meters

80 degree scanning system:

Scan Angle:	60 degrees
Estimated Total Swath Width – 60 degree scanner	520m
Estimated Percentage of Overlap:	50% or 100 %overlap between lines
Estimated average raw returns per square meter:	10

***Due to aircraft proximity to the ground, minor deviations from these parameters did occur.**

Please note the accuracy and the number of "Bald Earth" points measured was dependent on vegetation, water and the reflectivity of the surface. Typically waterand fresh or sealed black asphalt caused small voids in the LiDAR data.

To ensure full LiDAR coverage, lines were designed at 250 meters spacing, resulting in a 50% side overlap. With a typical flying height of 400-450 meters above ground, the width of the scanned area on the ground is approximately 520 meters. Data acquisition was completed on November 2,2009.

5. Data Processing

5.1 Field Quality Control

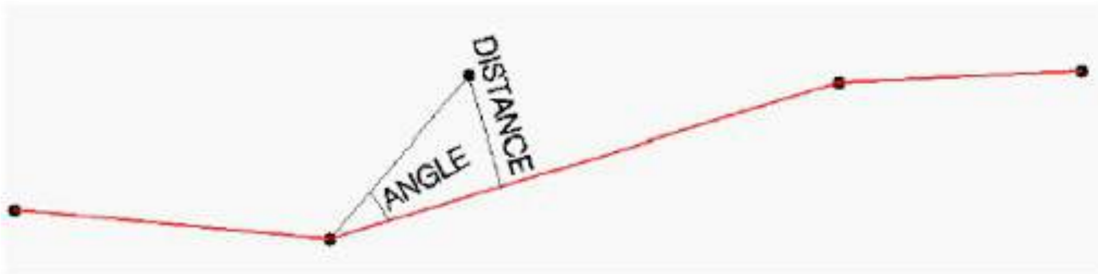
The aircraft positions are calculated by post-processing the GPS raw data at a 0.5-second interval for the entire flight. These positions are combined to the post-processed attitude information to generate a time tagged position and orientation solution at 200 Hz for the laser head. These values are used with the laser ranges and mirror angles to compute all the individual X, Y,and Z laser hits for each flight line.

Between four and ten flight lines are then merged together in the classification software, and run through a series of routines:

1. Removing erroneous points that are definitely below the ground surface.
2. Classify the laser returns, separating the ones that hit the ground from the ones that hit vegetation or buildings.

Below is an extract of the software manual's "Ground Classification":

> *"**Ground** routine classifies ground points by iteratively building a triangulated surface model.*
> *The routine starts by selecting some local points as sure hits on the ground. The application assumes that … the lowest point is a ground hit. The routine builds an initial model from selected low points. … The routine then starts moulding the model upwards by iteratively adding new laser points to it. Each added point makes the model follow the ground surface more closely.*
>
> *Iteration parameters determine how close a point must be to a triangle plane so that the point can be accepted to the model. **Iteration angle** is the maximum angle between point, its projection on triangle plane and closest triangle vertex. **Iteration distance** parameter makes sure that the iteration does not make big jumps upwards when triangles are large."*



3. The ground hits are then thinned, removing points that have an elevation difference of less than 5 cm compared to the other points within 2 meters horizontally, keeping the lowest points. This thinning method allows us to keep more points in steeper terrain and remove unnecessary points in flat areas. With these parameters, about two-third of the initial number of points are removed without losing any ground definition.
4. Laser returns hitting vegetation or buildings that are 1 metre or higher from ground level are separated and kept in a separate file. This gives a clean data set of vegetation and buildings without the "noise" of small brush and overlap classification.

The strips of ground thin data resulting from these steps are then loaded in the classification software and visually inspected for coverage or any classification anomalies. In case of data gaps, passes are re-flown over the specific areas, and the data processed and merged to the strip. Random elevation checks are made between ground points and kinematic points.

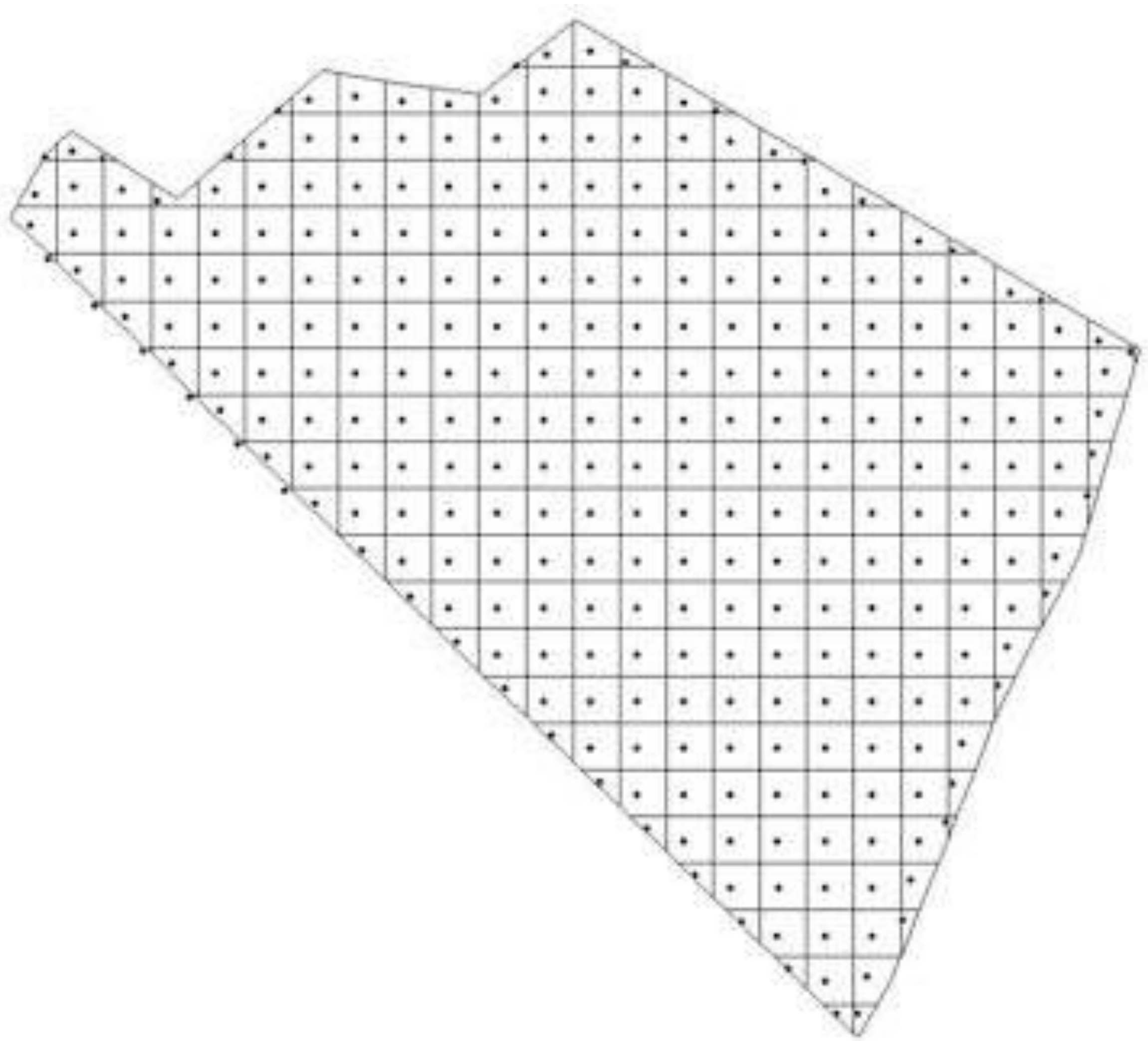
Once the coverage is accomplished, the ground thin strips are entered in gridding software for a colour coded three-dimensional view. This allows us to ensure no outlier points or vegetation hits are left in the ground data.

LiDAR Data was delivered on the following Survey Datum's

- Horizontal Datum – UTM, Zone 13
- Vertical Datum – ITRF92 / WGS84
- Units – Meters
- Geoid Model – Mexico97

6. Tile Layout

With the size of the project area and keeping the final files in a more workable size, we create a tile layout 500m x 500m.



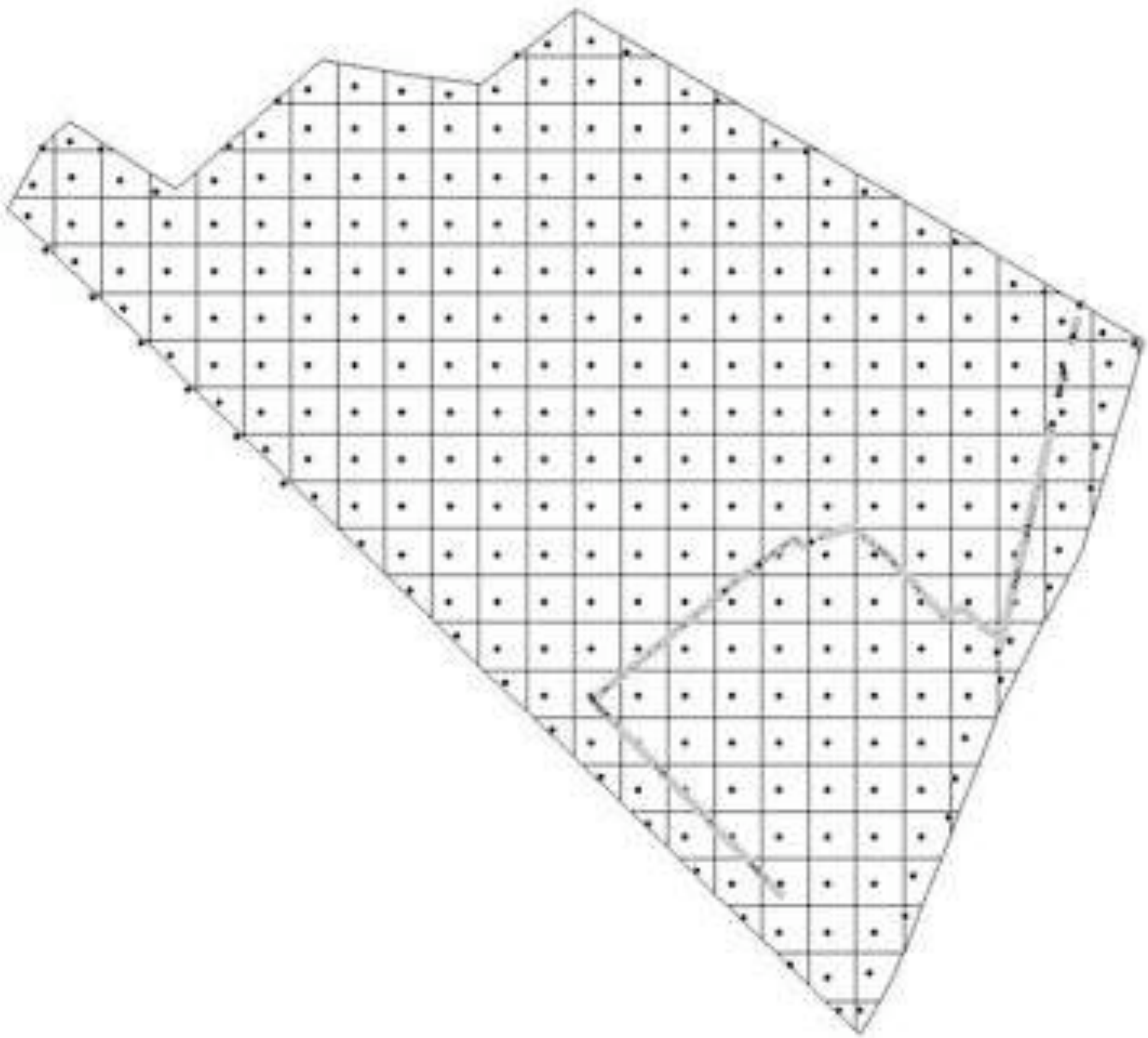
7. Post Processed Kinematic GPS Survey

A GPS kinematic survey was carried out to provide the client with a qualitative and quantitative assessment of the LIDAR accuracies. A mobile, truck mounted GPS unit, and stationary base station, collected simultaneous raw data at 0.5 second interval for post processing. The truck drove along open roads on the project where LiDAR coverage was available. This yields thousands of control points over just a few square kilometers.

These post-processed kinematic points have been closely monitored. If there was any uncertainty that the accuracy would exceed 8 centimetres, the points were rejected. Only high quality kinematic solutions were used to "ground truth" the project.

Kinematic GPS Survey

Kinematic GPS Survey



Kinematic GPS Route

8.0 Statistical Analysis and Accuracies

8. 1 Statistical Analysis

Statistics can be calculated on the elevation differences between the kinematic ground points and the LiDAR surface. A surface model was created from the ground thin data set, triangulating the ground points. The X,Y coordinates of the kinematic points were "transposed" onto the surface model (at the intersection of the triangle plane), and given and elevation. So each kinematic X,Y coordinate has now two elevations: one from the kinematic survey and one from the surface model. Then we calculate the difference between the two. By calculating the percentage of elevation differences (in absolute values) that falls within a certain range, this gives us a statistical analysis of the accuracy of the data. The same procedure was also applied to the aerial control points and static GPS survey points.

8.2 Accuracies

Hard Surface Road" kinematic derived QA/QC points were compared to the LiDAR surface. The results are as follows:

Number of Points: 8170

	(Meters)
Average dz	-0.005
Average magnitude	0.029
Root mean square	0.034
Std deviation	0.034

9. Typical Terrain & Land Cover

Upon field inspection, our survey crew fund areas of heavy/ very /thick in numerous areas with in the project area including grass from the N-S dirt road to the edge of the beach. The depth of the grass averaged approximate 30cm from the palm tree line to the edge of the beach. That grass appeared not to allow light penetration subsequently affecting the ability of the LiDAR to measure actual ground.

Appendix A

CALIBRATION REPORT

On the ALIS-80S LiDAR system

Oct 31, 2009

1.0 Introduction

The purpose of this report is to explain the procedures that Airborne Solutions takes to calibrate the ALIS-80S 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.

2.0 Lever Arms 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 helicopter 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 sensors 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.

2.1 Procedures

The aircraft was parked on a level surface. A surveyor's plum bob, laser level 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 this case mounted in a fixed wing aircraft the lever arms are reasonably short and much easier to measure in comparison to the helicopter used for illustration purposes.

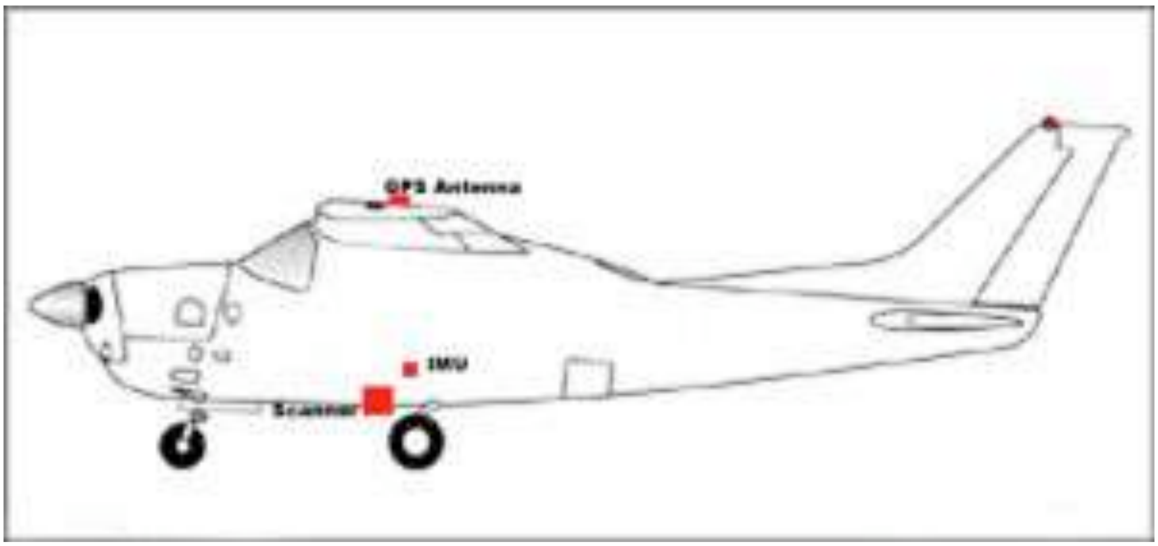
2.2 Values

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

Laser → GPS antenna	Laser → IMU
DX = -0.0239 m	**DX = 0.180 m**
DY = 0.2954 m	**DY = 0.212 m**
DZ = 1.1230 m	**DZ = 0.052 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.
(for illustration purposes only)

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



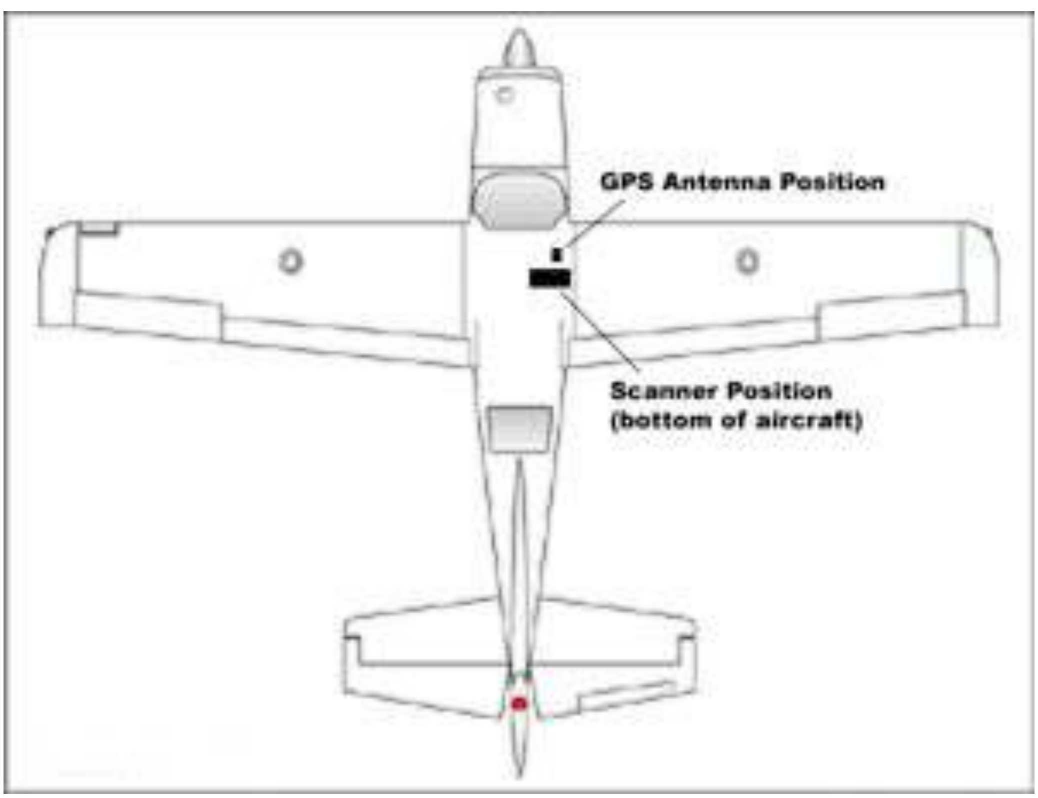


Figure 2 - DY lever arm for the GPS antenna, DY = +0.194 m (top view)

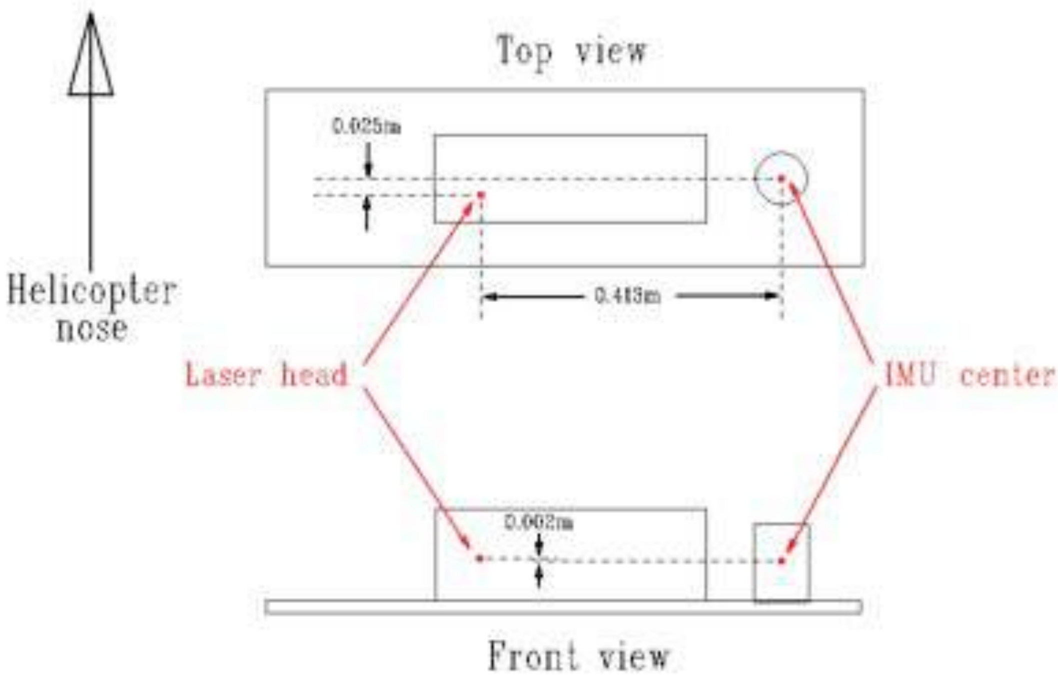


Figure 3 – Lever arms for the IMU

3.0 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 a surveyed area. This method is based on trial and error, and measuring the distance between identifiable features from different scan swaths.

3.1) 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. The laser does not reflect over water, therefore leaving a void 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.

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.

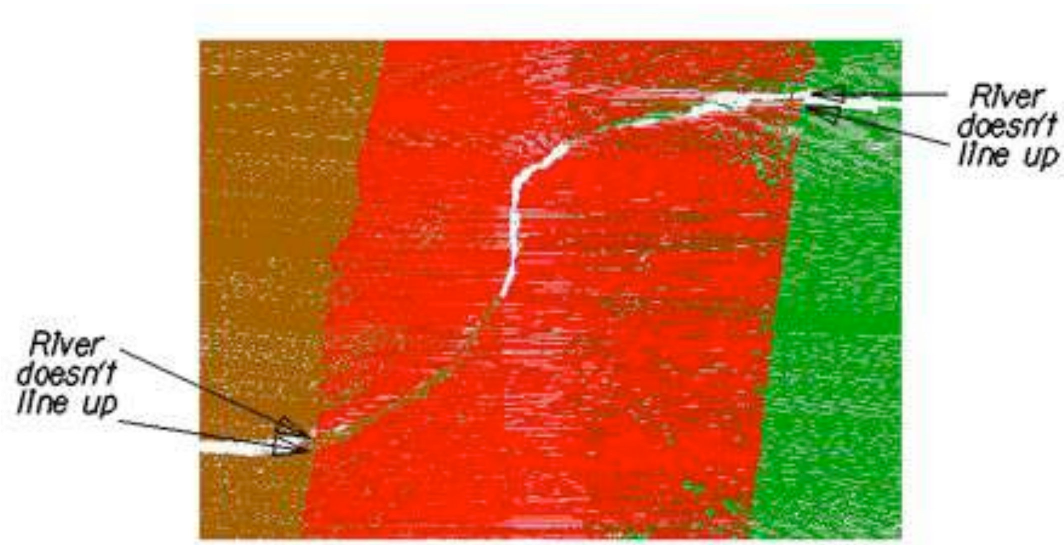


Figure 4 – Laser swaths not lining up (wrong heading offset)

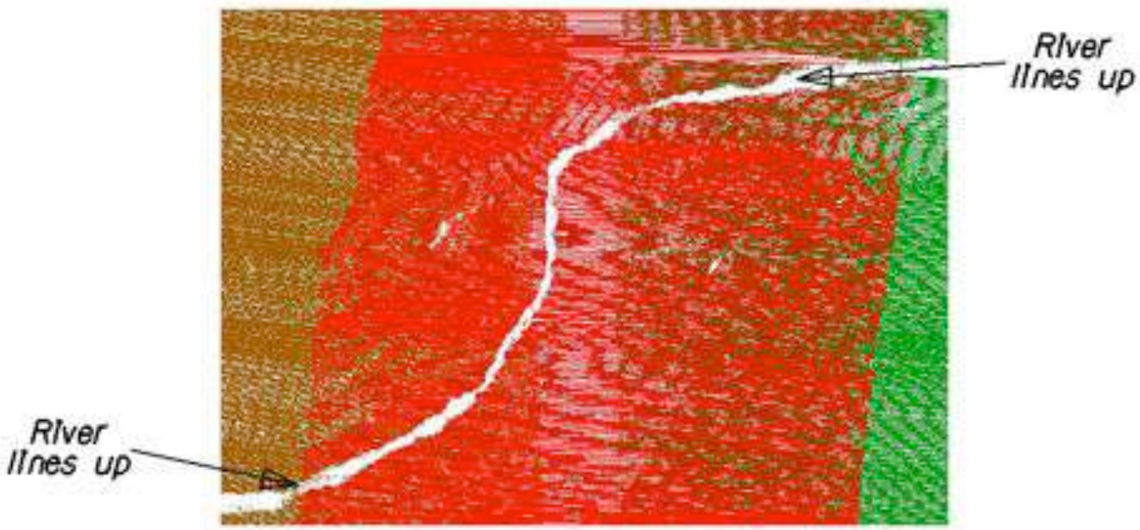


Figure 5 – Laser swaths lining up (proper heading offset)

3.2 Pitch and roll offsets

Once the heading offset has been determined, the pitch and roll offsets can be determined. The method we use is as follows: we fly over a previously surveyed building from opposite directions and visually see if the buildings line up at the surveyed corners.
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.

3.2.1 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.

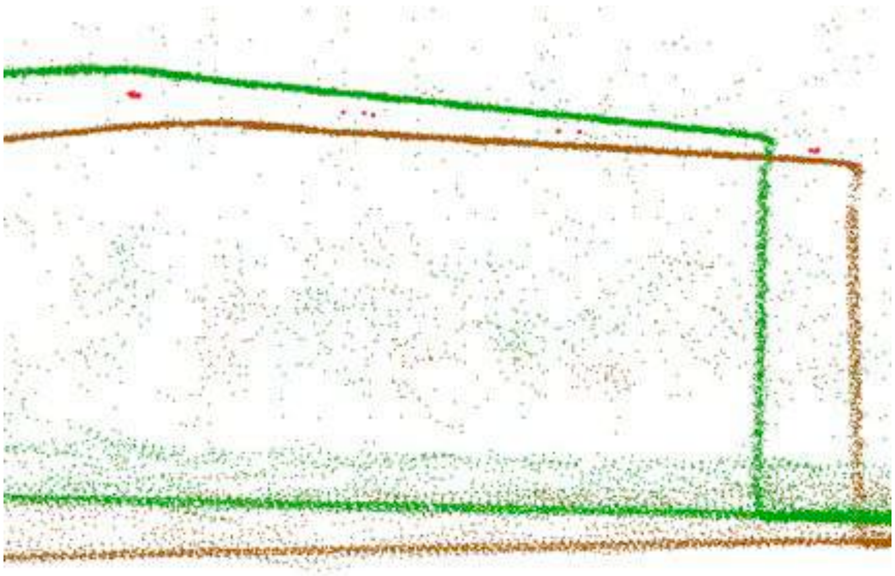


Figure 6 – Side view of two laser swaths with a one-degree roll offset error.

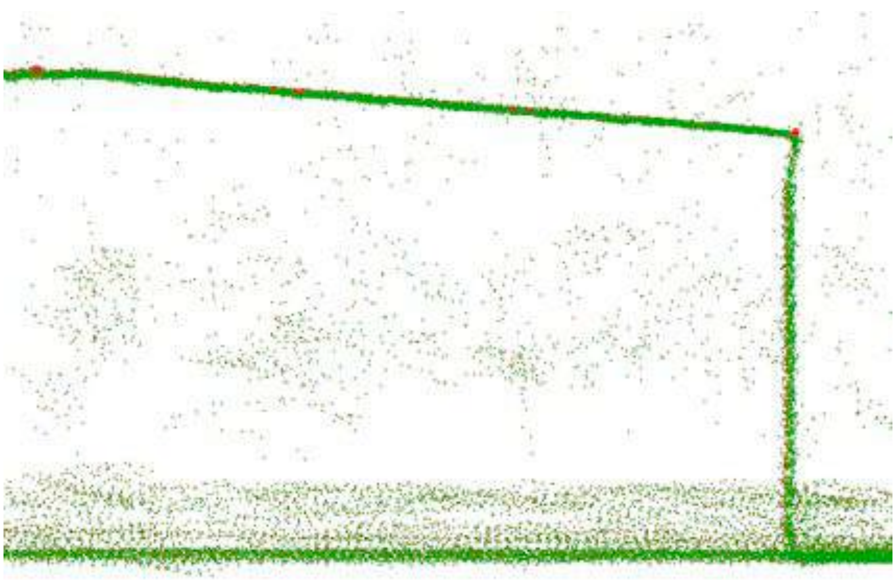


Figure 7 – Side view of two laser swaths with the proper roll offset.

3.2.2 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.

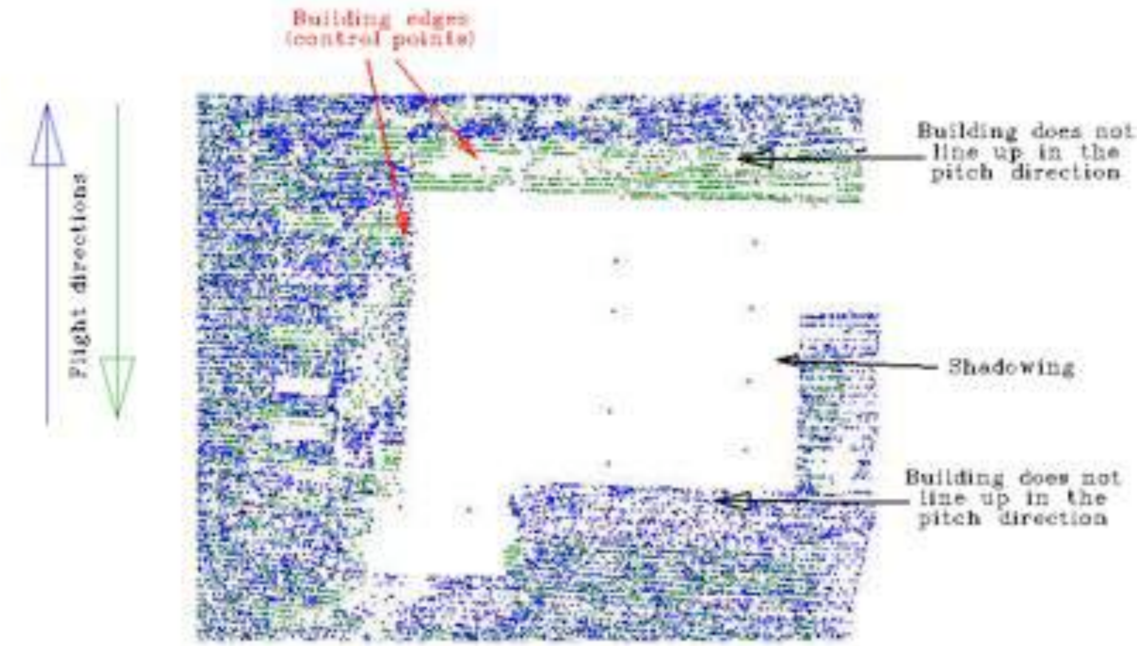


Figure 8 – Top view of two laser swaths with a one-degree pitch offset error.

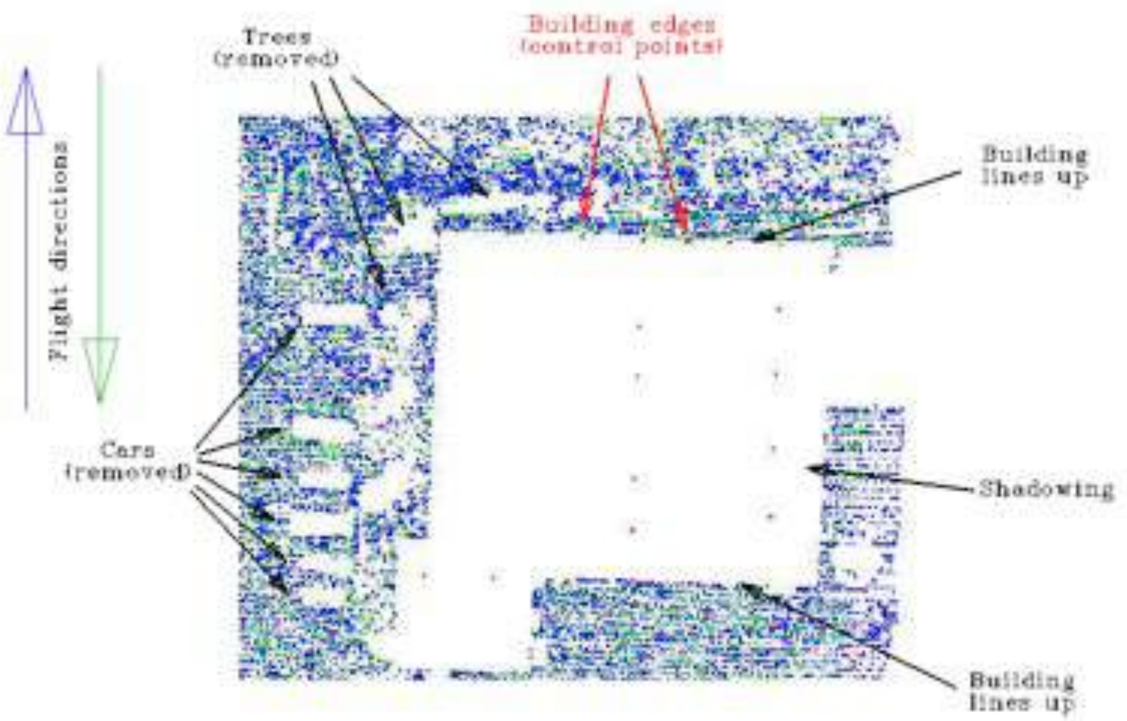


Figure 9 – Top view of two laser swaths with the proper pitch offset.

3.3 Offset values:

The present offset angles for the October 31st installation are:

```
Laser
Pitch:      0.0239 degree
Roll:      -0.2654 degree
Heading:   -0.01269 degree
```

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

4.1 Calibration - Kinematic survey

On every LiDAR project flown, our team 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 .5 second intervals for post processing. 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 centimetres. This yields thousands of control points over just a few square kilometres.

4.2 Calibration - Statistical analysis

Once the LiDAR Calibration data has been processed, points without losing any ground definition. a Triangulated Interpolation Network is created and compared to the post processed Kinematic GPS survey data.