ACCURACY ASSESSMENT OF COGS DRONE LIDAR SURVEY

Course: REMS 6085: Lidar Systems and Processing – Lab 3

Instructor: Rob Hodder

Abstract

Accuracy assessment of a drone Lidar survey (DJI Matrice 300 RTK, Zenmuse L1) conducted on 14 October 2022 of the Centre of Geographic Sciences (COGS) and surrounding areas, completed in accordance with Government of Canada Federal Airborne Lidar Data Acquisition Guidelines.

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ABBREVIATIONS

AOI – Area of Interest
AGL – Above Ground Level
ANPD – Aggregate Nominal Pulse Density
ASPRS – American Society for Photogrammetry and Remote Sensing
CGG 2013a – Canadian Geoid 2013a
CGVD 2013 – Canadian Geodetic Vertical Datum of 2013
COGS – Centre of Geographic Sciences
CQL – Canadian Quality Level
CSRS – Canadian Spatial Reference System
DCAOI – Data Collection Area of Interest
DTM – Digital Terrain Model
DSM – Digital Surface Model
D_z – Difference in Elevation
GETG – Geomatics Engineering Technology Diploma
GIS – Geographic Information Systems
GNSS – Global Navigation Satellite System
GPS – Global Positioning System
GRS 80 – Geodetic Reference System 1980
IMU – Inertial Measurement Unit
LAS – LASer File Format Exchange
LAZ – LASzip
LiDAR – Light Detection and Ranging
NAD 83 – North American Datum of 1983
NIR – Near Infrared
NVA − Non-Vegetated Vertical Accuracy
PDOP – Airborne GPS Positional Dilution of Precision
RGB – Red, Green, and Blue – The Major Wavelengths of Visible Light
RTK – Real-Time Kinematic
RMSE – Root Mean Square Error
$RMSE_z$ − The Vertical Linear RMSE in the Z Direction (Elevation)
SBET – Smooth Best Estimate of Trajectory
SI – International System of Units
TIN – Triangulated Irregular Network
UTM – Universal Transverse Mercator
VVA − Vegetated Vertical Accuracy
XYZ – Cartesian Coordinates – Easting, Northing, and Orthometric Height

INTRODUCTION

The survey was performed on 14 October 2022, during daytime, in overcast and light rain conditions. The AOI spanned UTM 20 N 328200 4973100 and UTM 20 N 329100 4972200, covering an area of approximately 165,000 square metres (m^2)[1], centred on COGS and surrounding areas. The drone pilot was Rob Hodder, COGS Faculty in Remote Sensing, who used a Zenmuse L1 sensor mounted on a DJI Matrice 300 RTK drone. Because the L1 sensor had dual Lidar and RGB capturing capabilities, not only were RGB values embedded in the raw point cloud, but an orthomosaic image of the DCAOI (spatial resolution of 2.18 centimetres per pixel) was also captured at the same time as the Lidar survey.

The survey was conducted for educational purposes. GETG students from the 2022 to 2023 cohort collected RTK carrier-phase GNSS control points for this survey, as part of their Lidar course. The raw point cloud and the RTK control point data was then used by GETG students for an assignment. The raw point cloud and the RTK control point data was later provided to GIS Graduate Certificate students for use in an assignment in their own Lidar course.

GIS Graduate Certificate students were required to import, process, and classify the raw Lidar point cloud from this survey. Next, GIS students were required to conduct a formal accuracy assessment of the drone survey according to the Government of Canada's *Federal Airborne LiDAR Data Acquisition Guideline Version 3.1*, which was based partly on ASPRS standards. This required students to compare the drone survey with the RTK GNSS control points using Bentley MicroStation CONNECT Edition and TerraScan (see **Appendix A**). Finally, students were required to create Bare Earth and Full Earth surfaces from the project point clouds.

Table 1 summarises the flight parameters of the drone survey. CQL1 standards state the degree of overlap must be at least 15% or greater; number of returns must be greater than two; sampling rate must be greater than 50 KHz; and point density (ANPD) must be greater than two points per square metre (points / m^2). The degree of overlap, the number of returns, the sampling rate, and point density of the survey all met CQL1 standards.

[1] Calculated from the total number of points in the survey (124, 381, 344), and the approximate point density value (760 points per square metre) in Table 1. This calculation was double-checked by measuring the area of the AOI in Bentley MicroStation CONNECT.

Table 1: Drone flight parameters. Descriptions sourced from 'lab3_accuracy.pdf' provided by Rob Hodder.

Date Acquired	14 October 2022
Altitude	80m AGL relative to takeoff point
Flight Speed	7.9 metres per second (m / s)
Overlap	60% side overlap
Number of Returns	Triple returns
Sampling Rate	160 Kilohertz (KHz)
Scanning Mode	Repetitive scanning
Colouring Mode	RGB colouring enabled
Point Density	Approximately 760 points per square metre (points / m^2)
Number of Classes in Raw Data	1 class only – Default (Class 1)
RGB Values Embedded in Point Cloud?	Yes
Time Values Embedded in Point Cloud?	Yes

SURVEY CONTROL

The RTK control points were collected by GETG students as part of their Lidar course in Autumn 2022. This was in accordance with CQL1 guidelines because a third-party (i.e. a party other than the main surveyor) collected the RTK points, It was presumed the points were collected after the drone survey was performed. If this was the case, this would also meet CQL1 standards.

The exact equipment and methods used by the GETG students to collect the RTK control points were not specified. Nevertheless, it was assumed the equipment used for the survey control was capable of two-to-five-centimetre accuracy (i.e. RTK carrier-phase GNSS equipment), as per CQL1 guidelines, because the accuracy of all RTK control points was found to be within two-to-five-centimetres.

Active or passive base station data (i.e., their locations), the number of satellites in view, the PDOP, the names and locations of monuments, the datetime stamps, and GNSS data (except for the Northing, Easting, and Orthometric Height of each control point) were also not provided. Again, it was assumed this missing information met CQL1 standards. Despite the lack of survey control photographs, the orthomosaic taken contemporaneously with the Lidar survey served as a useful reference for survey control point locations.

There were 27 control points in total. The selected control points were dispersed evenly throughout the AOI to assess the accuracy of a variety of land cover types in two broad categories: non-vegetated (NVA) and vegetated land (VVA). All quadrants of the AOI contained control points of both types, though areas of lesser interest contained fewer control points. All control points were accurate to less than five centimetres, presumably because they were collected using RTK GNSS equipment. This satisfied CQL1 guidelines because the control points had an accuracy of at least five centimetres, three times greater than the minimum vertical accuracy of 15 centimetres of the survey data being assessed.

Non-vegetated land refers to land not covered by vegetation. Non-vegetated land is typically gravelled, paved, or covered by very low vegetation, and is usually flat. Because of its flat topography, the errors are assumed to be distributed normally, meaning the accuracy threshold for the NVA points is the 95th Confidence Level. The NVA is the minimum requirement for any accuracy assessment of airborne survey data.

Vegetated land refers to land covered by vegetation. Since the height of vegetation cover on vegetated land can vary from short shrubs and weeds to tall trees, elevation errors vary with the height and density of ground cover. This means that a normal distribution cannot be assumed, and the 95th percentile must be calculated instead. Because VVA are less ideal land cover types, their accuracy threshold is relaxed compared to the NVA. Assessing the accuracy of VVA points is optional, but it was required for this project.

Table 2 details the topography and land cover type in each category, the number of control points captured in each land category for this survey, as well as the accuracy threshold required for each category.

Table 2: Summary table for each land category. Descriptions sourced from 'lab3_accuracy.pdf' provided by Rob Hodder.

	A (NVA)	B (VVA)
Topography	Flat	Varying – mostly flat; occasionally sloped, but no more than 10% grade.
Land Cover	Gravel	Grass / Vegetation
	Paved	Dirt / Mud
Number of Control Points in Survey	17	10
Accuracy Threshold	95th Confidence Level	95th Percentile

According to guidelines, the minimum number of control points for each land cover type is 20 (though 30 is preferred), but this is not a strict rule. The number of survey control points does not meet this threshold because of the small area of the AOI, but this requirement was waived for this survey.

Additionally, the minimum requirement, as per CQL1, is to sample five grid cells per square kilometre. Because the AOI was smaller than one square kilometre, the area component of this requirement was waived. However, while not all ten project blocks (see **Data Processing**) contained control points, eight blocks contained NVA points, and seven blocks contained VVA points. This fulfilled the above requirement of sampling more than five blocks for each type of control point.

DATA PROCESSING

The data processing workflow was relatively straightforward. To prepare for the import of the Lidar data into MicroStation, a new DGN file in MicroStation was created. Within the DGN file, the AOI was first imported with the correct spatial reference system (see **Appendix B**). Second, an array of ten 200 metre by 200 metre square blocks was created to overlay the AOI and numbered in ascending order from North to South. Third, the SBET was imported into the DGN file in the correct spatial reference system, and then split using the AOI polygon to keep individual survey flightlines (eight in total), and remove calibration flightlines. Fourth, the NVA and VVA control points were imported into the DGN file. This required manual editing of the CSV file so that it was in a format (i.e. XYZ coordinates only) which MicroStation would accept. Finally, the orthomosaic was attached to the DGN as a reference for the accuracy assessment procedures. **Figure 1** displays the final MicroStation file and the results of these steps.

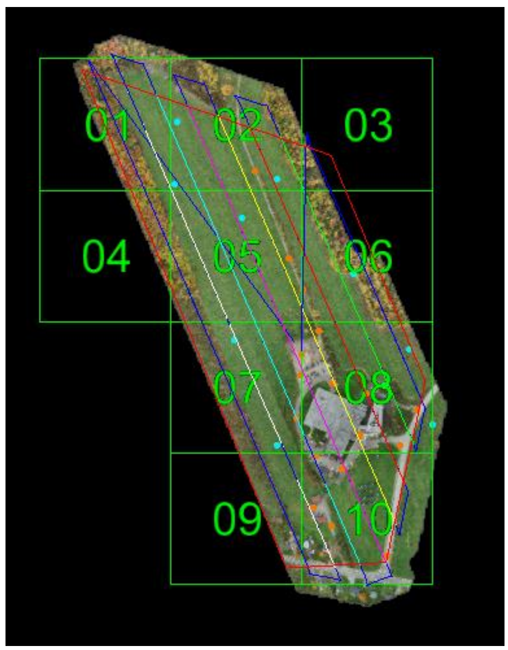


Figure 1: Screenshot of the results of the workflow within MicroStation to prepare the DGN file for the import of the raw Lidar point cloud. Each element is coloured: the AOI is red; the project blocks are green; the SBET is blue; the individual survey flightlines of the SBET are multi-coloured; the NVA points are orange; and the VVA points are turquoise. The orthomosaic is also shown.

The second series of steps involved the import of the raw lidar data provided in the initial project files (see **Appendix C**). First, a TerraScan project was initialised. The data type was set to LAS 1.2, and the project attributes were modified to also allow the import of the embedded Colour and Time values within the raw data. Second, with the AOI selected as the fence, all points within the AOI were imported into the ten project blocks, and saved as ten separate LAS files, labelled *L1000001.las* to *L1000010.las*. **Figure 2** displays the results of this step.

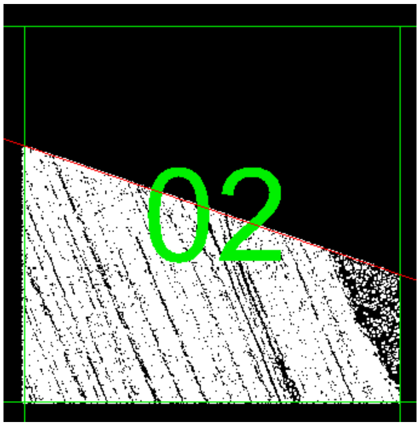


Figure 2: Screenshot of the result of the workflow in TerraScan to import the raw point cloud into the ten project blocks. Note, only one project block can be opened at a time due to memory constraints. Block 02 has been opened in this instance.

The third series of steps involved deriving and writing survey flightline information to the newly created project LAS files, since flightline information was not embedded in the provided data. This involved writing and running a macro on the project points which deduced the flightline of each point, using the split flightlines derived from the first series of steps.

This macro set the flightline number to 99 for any and all points regardless of their current or default flightline classification; deduced flightlines using the trajectories and point timestamps of the survey flightlines; and deleted any points which were not relabelled in the previous step, and which still retained a flightline number of 99. **Figure 3** shows points before and after the Deduce Flightlines macro was run.

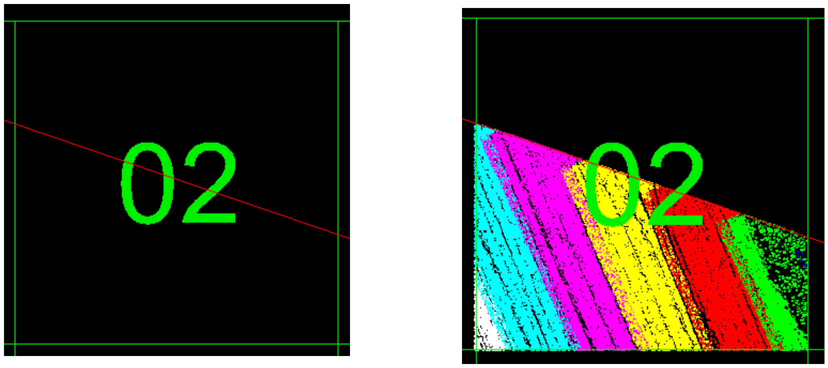


Figure 3: Screenshots of the result of the workflow in TerraScan to derive and write flightline information to each project block. Block 02 is displayed. The left image does not show any points because the points lacked embedded flightline information. The image on the right shows points coloured by flightline, as they now have flightline information written to them.

The fourth series of steps involved the classification of overlapping points using the newly derived flightline information. Overlapping points are points found in two or more flightlines. These points needed to be reclassified into the Overlap class (Class 12) to mitigate the greater frequency of errors found at the edges of flightlines.

To classify the overlapping project points, another macro was needed. First, all points were classified to the Default class (Class 1), if there were not already. Second, the overlapping areas were cut to keep only a 40 degree (°) corridor. **Figure 4** shows the points before and after the Cut Overlap macro was run.

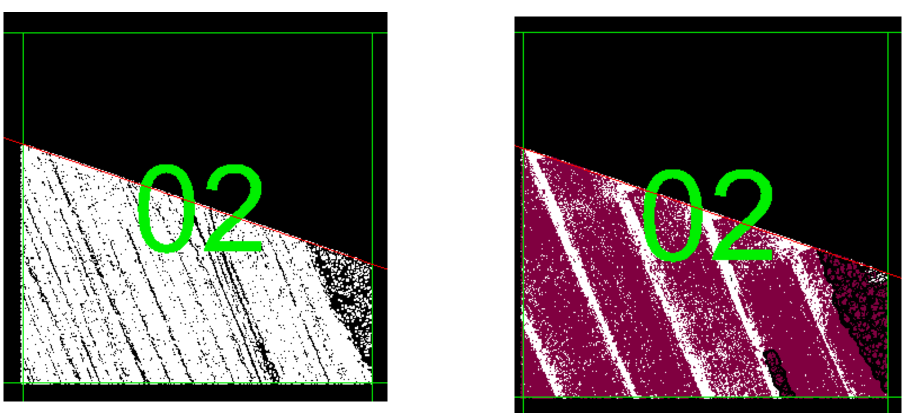


Figure 4: Screenshots of the result of the workflow in TerraScan to reclassify all overlapping points, as seen on Block 02. The left image displays the Default class (Class 1, white) only, with the overlapping points not yet classified to the Overlap class (Class 12, mauve). The right image shows Default and Overlap points, after the macro has run.

The fifth series of steps involved the final automated classification of all non-overlapping points. This required one final macro to be run on all project points in the Default class (Class 1). The first step of classification was to reclassify noise points. The first noise clean-up routine removed all isolated points (points too separated from other points) from the Default class, and moved them to the Low Points class (Class 7). The second noise clean-up routine removed low points (points much lower than other points) from the Default class, and also moved them to the Low Points class.

Once the noise points were reclassified, the Ground class (Class 2) was classified using default parameters. Next, vegetation was classified using the Height Above Ground function: points between 0.05 metres and 0.5 metres above ground were placed in the Low Vegetation class (Class 3); points between 0.5 metres and 2 metres above ground were placed in the Medium Vegetation class (Class 4); points between 2 metres and 80 metres above ground were placed in the High Vegetation class (Class 5).

Finally, buildings were classified by moving points from the High Vegetation class to the Building class (Class 6) if certain height and area parameters were met. Some high points in Block 08, which were well-above ground, were originally classified as High Vegetation (Class 5). These were missed by the macro, and as a result, were manually assigned to Low Points (Class 7). **Figure 5** displays the results of the automated classification of the project points.

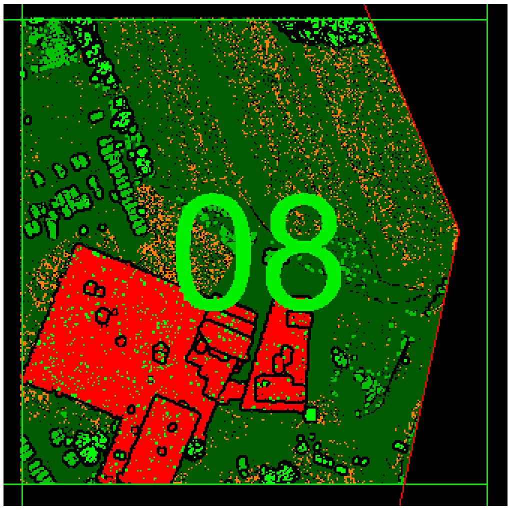


Figure 5: Screenshots of the result of the final classification of the project points, with the Ground class (Class 2, orange), Low Vegetation (Class 3, dark green), Medium Vegetation (Class 4, intermediate green), High Vegetation (Class 5, bright green), and Buildings (Class 6, red) all visible. Default (Class 1), Low Points (Class 7) and Overlap (Class 12) are not visible.

Table 3 summarises the classes present in the final, classified project blocks.

Table 3: The list of classes used for classification of the project points.

Class Number	*Class Description*
Class 1	Default / Processed but Unclassified
Class 2	Ground
Class 3	Low Vegetation
Class 4	Medium Vegetation
Class 5	High Vegetation
Class 6	Buildings
Class 7	Low Points
Class 12	Overlap

The sixth series of steps involved the accuracy assessment of the Lidar points by comparing them to the control points in each land category. These steps are detailed in **Accuracy Assessment**.

The final series of steps was the creation of the Bare Earth (DTM) and Full Earth (DSM) surfaces from the classified and assessed project blocks. One set of each surface type was created, resulting in ten Bare Earth surfaces and ten Full Earth surfaces, one from each block. This required use of the *Batch Convert/Reproject* tool in Global Mapper Pro. The project LAS files were imported into Global Mapper Pro twice – once for the Bare Earth surface and once for the Full Earth surface.

Once the files were loaded into the *Batch Convert/Reproject* tool, file name conventions and a bin size of 0.5 metres (surface resolution) were set, and the classes included in each surface were selected. The Bare Earth surface required only the Ground class (Class 2), whereas the Full Earth surface required all classes except Default (Class 1), Low Points (Class 7), and Overlap (Class 12). **Figure 6** displays a screenshot of the combined Bare Earth surface. **Figure 7** displays a screenshot of the combined Full Earth surface. **Appendix F** contains a cartographically correct project map of the AOI, with the Full Earth surface displayed.

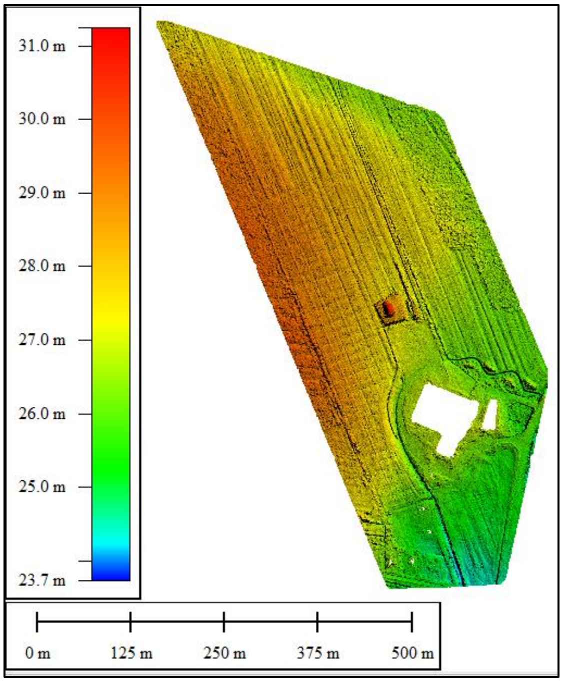


Figure 6: A screenshot from Global Mapper Pro of the combined Bare Earth surface (DTM) of all project blocks. Only the Ground class (Class 2) is included.

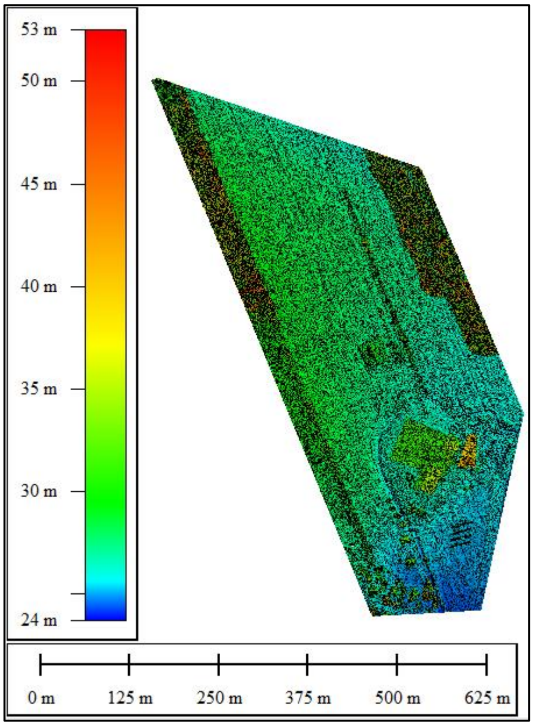


Figure 7: A screenshot from Global Mapper Pro of the combined Full Earth surface (DSM) of all project blocks. Only Ground (Class 2), Low Vegetation (Class 3), Medium Vegetation (Class 4), High Vegetation (Class 5), and Buildings (Class 6) are included.

ACCURACY ASSESSMENT

The workflow to calculate the accuracy assessment was also straightforward. The supplied control points were again manually converted into a format which TerraScan could read, except this time the Point IDs were also included with the XYZ coordinates. **Appendix D** contains the formatted NVA and VVA points imported into TerraScan. Second, the *Output Control Report* tool in TerraScan was executed to analyse the quality of the survey points against the control points. It was run twice for each accuracy category, i.e., the NVA and the VVA.

When the *Output Control Report* tool was run, TerraScan built a TIN – a common method of representing a three-dimensional surface – from all the Ground points within a project block. Next, the Easting and Northing of each control point was used to interpolate an elevation value from the TIN (i.e. Kriging). This interpolated value was then compared to the actual elevation of the known point. The difference calculated between the two elevation values (the D_z) was the error. Once the D_z was calculated for each point, a report of these errors was created, along with a set of summary statistics such as the magnitude of error, the standard deviation, the RMSE, the minimum D_z, the maximum D_z, and others.

Since TerraScan does not automatically compute the 95% Confidence Interval for the NVA points or the 95th Percentile for the VVA points, these were calculated manually using Microsoft Excel. To calculate the 95% Confidence Interval, the $RMSE_z$ value for the NVA points was multiplied by 1.96. The 95th Percentile (the number greater than 95% of the VVA D_z values) could only be calculated once the absolute D_z values of the VVA points were calculated first. **Appendix E** contains the full output control reports, and the summary statistics for the NVA and VVA points.

Once the control reports were generated, high error values (i.e. NVA or VVA points with D_z values greater than 0.06 metres) in both categories were visually checked in two ways. The first method involved examining the orthomosaic to determine the land cover of each control point. The second method involved taking vertical profiles in TerraScan, and investigating how far above or below the survey ground surface the control points were situated.

The $RMSE_z$ of the NVA points was high. The average D_z was -0.071 metres, or -7.1 centimetres, and the greatest D_z was -0.116, or -11.6 centimetres. These high error values were primarily due to errors in the automatic classification. The Final Classification macro mistakenly identified gravel surfaces as Low Vegetation, possibly because of the unevenness and slight elevation changes seen in gravel surfaces. **Figure 8** shows NVA points 114 and 116 on gravel surfaces, along with their vertical profiles.

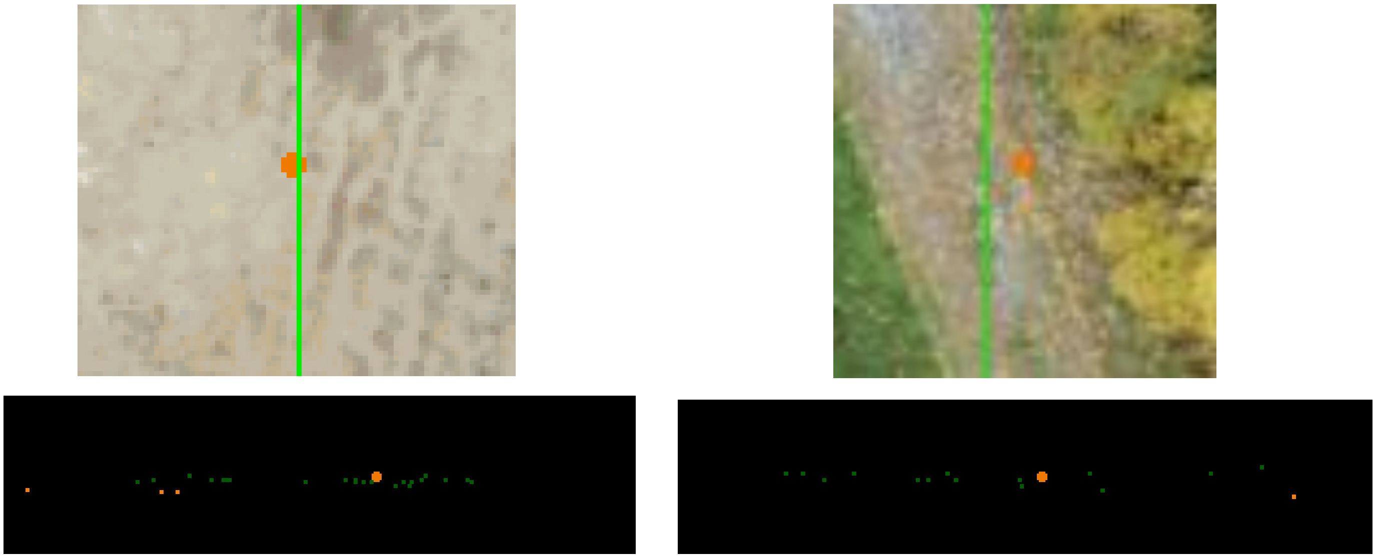


Figure 8: Screenshots of the land cover and vertical profiles of NVA points 114 (Left, large orange point) and 116 (Right, large orange point), showing how the uneven gravel surface has been classified as Low Vegetation (Class 3) instead of Ground (Class 2).

Curiously, this pattern was also seen in NVA points on asphalt surfaces. Asphalt surfaces were much more even and smooth, yet the macro also continually classified these asphalt surfaces as Low Vegetation. **Figure 9** shows two NVA points – 105 and 111 – on asphalt surfaces, along with their vertical profiles.

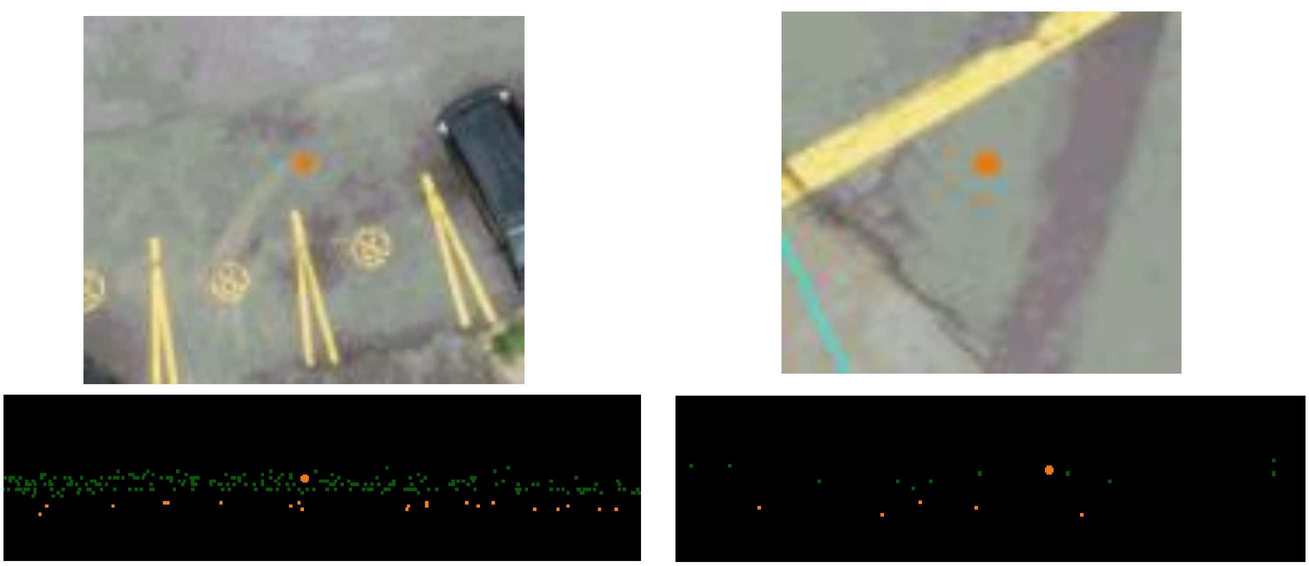


Figure 9: Screenshots of the land cover and the vertical profiles of NVA points 105 (Left) and 111 (Right), showing how the even asphalt surface has been placed in the Low Vegetation class (Class 3) instead of the Ground class (Class 2).

These points were not removed or deactivated because they were not blunders, i.e. extremely large errors greater than three standard deviations (0.027 multiplied by 3, which equals 0.081) of the NVA sample. However, errors in NVA points 104, 107, and 108 did meet the threshold of a blunder. The cause of these blunders was undetermined. These failures could be due to a failure on the part of the automatic classifier. In the case of NVA point 108, the large errors may be because the point was located close to the edge of the road, where elevation tends to dip.

Despite these errors in the automatic classifier, edits were not made to the automatic classifier, and further manual classification of these points was not performed. These blunder points were retained because while the errors were high, the $RMSE_z$ of the NVA points still met CQL1 guidelines. **Figure 10** shows the land cover and vertical profiles of these three NVA points.

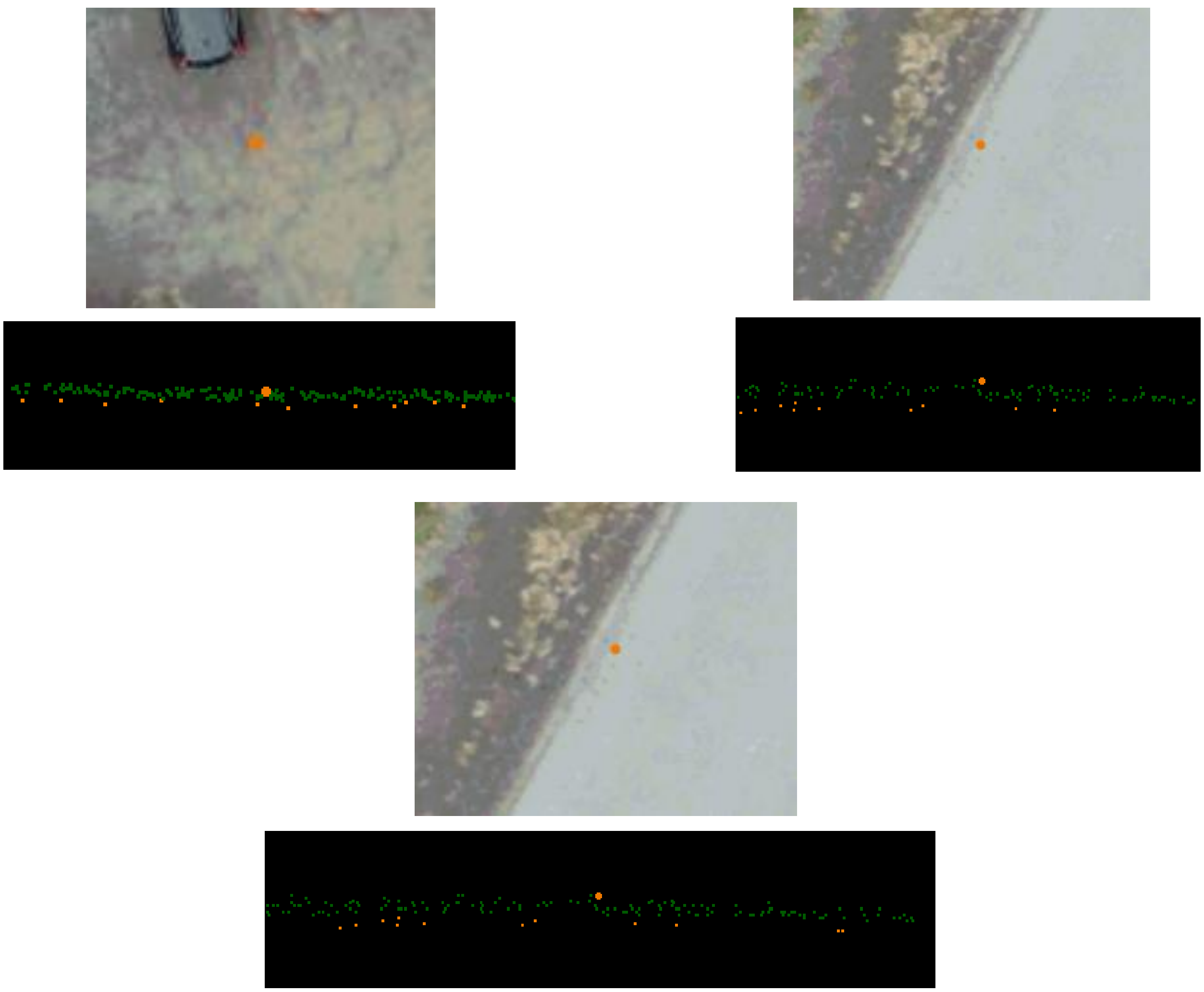


Figure 10: Screenshots of the land cover and the vertical profiles of NVA points 104 (Left), 107 (Right), and 108 (Bottom), showing further failures in the automatic classifier.

The only NVA point that was removed was point 115, because it was placed on grassy, vegetated land, and was therefore placed in the wrong land category. **Figure 11** shows the land cover and vertical profile of point 115.

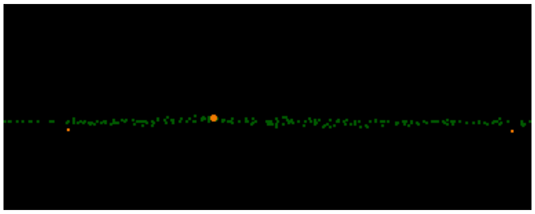
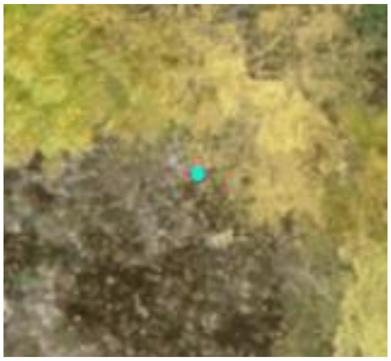


Figure 11: Screenshots of the land cover and vertical profile of NVA point 115, showing its placement on grassy, vegetated land.

The D_z values of the VVA points were much lower than the D_z values of the NVA points. Three VVA points had high D_z values: these were points 207, 209, and 213. Point 213 was outside the AOI and the DCAOI, meaning its corresponding survey point was not scanned during the survey. This meant that an elevation value for this point could not be interpolated using the TIN. Point 213 was automatically removed by the *Output Control Report* tool, no further action was necessary. **Figure 12** shows the location of point 213.

Figure 12: Screenshot of VVA point 213, which was well outside the AOI, and for which no elevation value could be interpolated by the TIN.

Similar to the NVA points placed on gravel and asphalt surfaces, the Ground surface below point 207 was well below the Vegetated surface. In the case of point 207 this was by design, because it was a VVA point. While its elevation was not successfully interpolated, point 207 was still retained. **Figure 13** shows the location of point 207 and its vertical profile.



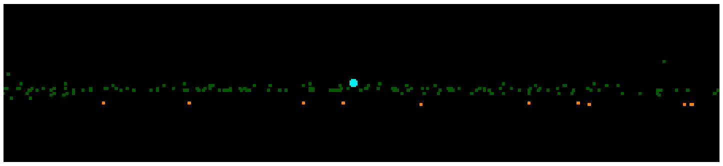


Figure 13: Screenshots of the land cover and vertical profile of VVA point 207.

The only VVA point which was removed was point 209. It was placed on vegetated land covered by tall, thick vegetation. This meant the Lidar was not able to penetrate through this vegetation to sense the Ground surface under the canopy. Consequently, when a vertical profile of point 209 was taken, there was no continuous surface classified as Ground below this point. This would have affected the interpolation of the elevation value of point 209 by the *Output Control Report* tool, hence the high error value. **Figure 14** shows the location and vertical profile of point 207.

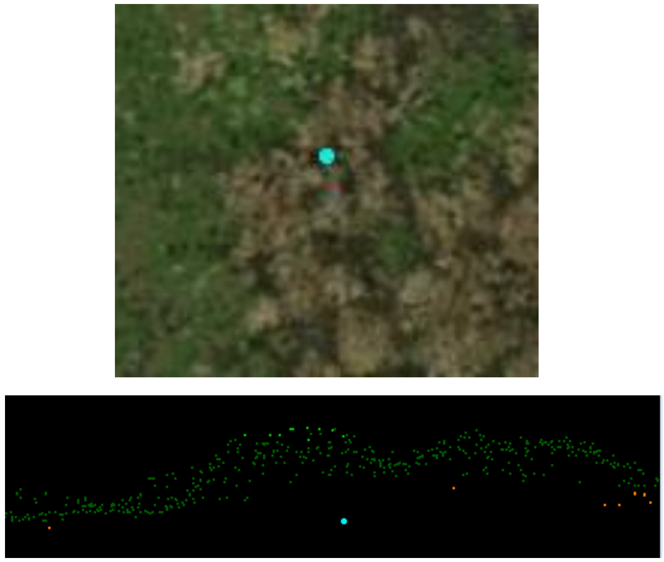


Figure 14: Screenshots of the land cover and vertical profile of VVA point 209, showing the lack of a continuous ground surface under the point.

Table 4 shows the summarised accuracy statistics of the NVA and VVA points.

Table 4: Summary accuracy statistics generated by TerraScan for the NVA and VVA points. Modified in Excel to calculate the 95% Confidence and the 95th Percentile values for the NVA and VVA points respectively.

Summary Statistics	*NVA Points*	*VVA Points*
Average D_z	-0.071	-0.015
Minimum D_z	-0.116	-0.085
Maximum D_z	-0.025	0.024
Average Magnitude	0.071	0.029
Root Mean Square	0.075	0.038
Standard Deviation	0.027	0.037
95% Confidence	0.147	*N / A*
95th Percentile	*N / A*	0.070

SUMMARY

The NVA and VVA values fell within CQL1 guidelines. While the NVA errors were high, the 95% Confidence Interval of the NVA points (0.147 metres or 14.7 centimetres) fell below the 95% Confidence Interval specified in the CQL1 guidelines (19.6 centimetres). Many of the high error values were due to a failure in the automatic classifier. But these relatively minor errors were not rectified. The only NVA point removed was a point placed on the wrong land cover type.

The VVA errors were much better than the NVA, even accounting for the relaxed standards for the VVA in CQL1 guidelines. The 95th Percentile of the VVA points (0.07 metres, or 7 centimetres) was far lower than the 95th Percentile for VVA points specified in CQL1 guidelines (30 centimetres). Two VVA points were removed. One of these points fell outside the AOI and DCAOI. The other point was placed under thick vegetation, which the NIR laser of the Zenmuse L1 sensor could not penetrate.

Many details of this survey were not specified. If the the IMU specifications of the DJI Matrice RTK 300, or the lever-arm offsets of the IMU, GPS receiver, and scanning mirror were provided, a more comprehensive assessment could have been written.

Additionally, many details of the RTK GNSS control point collection were also unspecified. Assuming these unknown or unspecified details of the survey also met CQL1 guidelines, then this project should also fall within CQL1 guidelines.

Of course, improvements could have been made to the automatic classifier, and manual classification of problematic surfaces could also have been performed. Since CQL1 guidelines were met or exceeded, the relatively minor errors in the NVA and VVA points were deemed tolerable. The additional effort required to rectify these errors was considered unnecessary.

APPENDIX A: EQUIPMENT USED

The following tables list the equipment used during the field component of this project (**Table 5**), and the software used (**Table 6**) during the accuracy assessment. If other equipment was used, it was not specified.

Table 5: List of equipment used. Descriptions sourced from 'lab3_accuracy.pdf' provided by Rob Hodder.

Sensor	Zenmuse L1 (Dual Lidar and RGB).
Drone	DJI Matrice 300 RTK Drone.
RTK Point Collection	Unspecified GNSS RTK Equipment

Table 6: List of software used and descriptions of their uses.

Bentley MicroStation CONNECT Edition	CAD software platform. Contains various project elements in vector format, such as the AOI, project blocks, SBET, derived flightlines, and the NVA and VVA control points.
TerraScan	Main application in TerraSolid software family for managing and processing point clouds. Used to import, process, and classify the project point cloud.
Microsoft Excel	Spreadsheet software with computation capabilities. Used to manually edit the CSV files containing the RTK control points, and calculate additional summary statistics.
Global Mapper Pro	GIS software package used to create Bare Earth and Full Earth surfaces from the project blocks, and the project map in **Appendix F**.

APPENDIX B: SPATIAL REFERENCES USED

Table 7 lists the projected coordinate system, datums, geoid model, and reference ellipsoid used for this project.

Table 7: The projected coordinate system, datums, geoid model, and reference ellipsoid, and units used for the project.

Projected Coordinate System	UTM Zone 20 North (20 N).
Horizontal Datum	NAD 83 CSRS
Vertical Datum	CGVD 2013
Geoid Model	CGG 2013 a
Reference Ellipsoid	GRS 80
Units	Metric / SI Units – metres (m), square metres (m^2)

APPENDIX C: PROJECT FILES, METADATA, AND SOURCES

The following tables list the sources of data for this project (**Table 8**), the initial project files provided (**Table 9**), and the final list of digital deliverables (**Table 10**).

Table 8: Sources of survey data.

Drone Pilot	Rob Hodder (COGS Faculty, Remote Sensing / REMS 6085 Course Instructor)
Project Specifications and Descriptions	Rob Hodder. Specifications and descriptions provided in 'lab3_accuracy.pdf'
Initial Project Files	Ron Hodder. Retrieved from the following path: \\ *nas* \ *RS* \ *REMS_6085* \ *Lab3*.
RTK GNSS Points	GETG students from the 2022 to 2023 cohort.

Table 9: Initial project files provided in *C:\ lab3* folder. Retrieved from the following path: \\ *nas* \ *RS* \ *REMS_6085* \ *Lab3*. Descriptions sourced from 'lab3_accuracy.pdf' provided by Rob Hodder.

Folder Path \ File Name	*Description*
Reference \ AOI.dgn	MicroStation DGN file containing the survey AOI. Points were loaded within this extent, and trajectories were clipped to this extent.
Lidar \ COGS_L1_nad83CSRSutmz20_cgvd2013.laz	Raw LAZ file for this project.
Ortho \ ortho.tif	RGB orthomosaic from drone flight, captured at the same time as the Lidar survey. 2.18 cm per pixel resolution.
RTK \ NVA.csv	RTK points for NVA assessment.
RTK \ VVA.csv	RTK points for VVA assessment.
sbet \ DJI_20221014130323_0001_Zenmuse-L1-mission_sbet.out	SBET (combined, complete flightline trajectories) for the project, consisting of eight survey lines and eight calibration lines.

Table 10: List of digital deliverables. Descriptions sourced from 'lab3_accuracy.pdf' provided by Rob Hodder.

Lab3 \ Folder Path \ File Name(s)	*Description*
Lab3 \ Francis_Lab3_report.pdf	Digital copy of this report.
Lab3 \ COGS_L1.dgn	The final DGN project created in MicroStation. Includes: the AOI element; labelled project blocks; complete SBET; cut flightlines and trajectories; NVA points; VVA points; and the orthomosaic, all on separate levels.
Lab3 \ blocks \ L1000001.las **Lab3 \ blocks \ L1000002.las** **Lab3 \ blocks \ L1000003.las** **Lab3 \ blocks \ L1000004.las** **Lab3 \ blocks \ L1000005.las** **Lab3 \ blocks \ L1000006.las** **Lab3 \ blocks \ L1000007.las** **Lab3 \ blocks \ L1000008.las** **Lab3 \ blocks \ L1000009.las** **Lab3 \ blocks \ L1000010.las**	Final classified LAS tiles in LAS 1.2 format, numbered in ascending order from North to South, with a tile size of 200 metres by 200 metres.
Lab3 \ blocks \ Lab3_COGS.prj	TerraScan project file.
Lab3 \ macros \ deduceFlightlines.mac	TerraScan macro used to deduce flightlines in project points.
Lab3 \ macros \ classifyOL_40.mac	TerraScan macro used to classify and cut overlap in project points.
Lab3 \ macros \ finalClassification.mac	TerraScan macro used for final classification of project points.
Lab3 \ reports \ import_points.txt	The report created by importing the points in the raw LAZ into the project blocks, fenced by the AOI.
Lab3 \ reports \ deduceFlightlines.txt	The report created by running the Deduce Flightlines macro on the project blocks.
Lab3 \ reports \ cutOL.txt	The report created by running the Cut Overlap macro on the project blocks.
Lab3 \ reports \ finalClassification.txt	The report created by running the Final Classification macro on the project blocks.
Lab3 \ RTK \ NVA_pxyz.csv	TerraScan 'known point' files for the NVA assessment group. Manually formatted to work in TerraScan. Also included in Appendix D.
Lab3 \ RTK \ VVA_pxyz.csv	TerraScan 'known point' files for the VVA assessment group. Manually formatted to work in TerraScan. Also included in Appendix D.
Lab3 \ RTK \ NVA_ControlReport.txt	Output control report from TerraScan for the NVA points.
Lab3 \ RTK \ VVA_ControlReport.txt	Output control report from TerraScan for the VVA points.
Lab3 \ RTK \ accuracy_assessment.xlsx	Excel file compiling all accuracy assessment results (i.e. VVA and NVA) in separate

	worksheets. Includes 95% confidence and 95th percentile calculations. Also included in Appendix E.
Lab3 \ surfaces \ L1000001_DTM.tif **Lab3 \ surfaces \ L1000002_DTM.tif** **Lab3 \ surfaces \ L1000003_DTM.tif** **Lab3 \ surfaces \ L1000004_DTM.tif** **Lab3 \ surfaces \ L1000005_DTM.tif** **Lab3 \ surfaces \ L1000006_DTM.tif** **Lab3 \ surfaces \ L1000007_DTM.tif** **Lab3 \ surfaces \ L1000008_DTM.tif** **Lab3 \ surfaces \ L1000009_DTM.tif** **Lab3 \ surfaces \ L1000010_DTM.tif**	Bare Earth (DTM) surfaces comprising the project area. 1 surface per block. 0.5 metre spatial resolution.
Lab3 \ surfaces \ L1000001_DSM.tif **Lab3 \ surfaces \ L1000002_DSM.tif** **Lab3 \ surfaces \ L1000003_DSM.tif** **Lab3 \ surfaces \ L1000004_DSM.tif** **Lab3 \ surfaces \ L1000005_DSM.tif** **Lab3 \ surfaces \ L1000006_DSM.tif** **Lab3 \ surfaces \ L1000007_DSM.tif** **Lab3 \ surfaces \ L1000008_DSM.tif** **Lab3 \ surfaces \ L1000009_DSM.tif** **Lab3 \ surfaces \ L1000010_DSM.tif**	Full Earth (DSM) surfaces comprising the project area. 1 surface per block. 0.5 metre spatial resolution.

APPENDIX D: CONTROL POINT INFORMATION TABLES

The following tables list the Easting, Northing, Orthometric Height in metres (m) of each NVA (**Table 11**) and VVA point (**Table 12**).

Table 11: The X, Y, Z coordinates of the NVA points.

Point ID	*Easting (m)*	*Northing (m)*	*Orthometric Height (m)*
118	328631.079	4972836.763	27.489
117	328683.237	4972704.668	27.865
116	328703.557	4972656.107	27.574
115	328728.544	4972592.256	27.100
114	328702.908	4972557.771	27.085
113	328700.451	4972526.112	27.141
112	328694.645	4972460.396	26.623
111	328723.160	4972403.856	26.487
110	328749.111	4972514.847	26.732
109	328800.873	4972498.535	26.313
108	328878.750	4972473.444	26.316
107	328853.459	4972419.116	25.980
106	328790.772	4972435.331	26.846
105	328763.233	4972383.064	26.236
104	328720.882	4972323.928	25.606
103	328746.915	4972297.341	25.309
100	328832.891	4972251.754	24.739

Table 12: The X, Y, Z coordinates of the VVA points.

Point ID	*Easting (m)*	*Northing (m)*	*Orthometric Height (m)*
213	328902.122	4972450.809	25.517
211	328665.410	4972420.072	27.757
210	328598.704	4972578.976	28.745
209	328828.852	4972509.233	26.004
208	328865.453	4972564.896	26.140
207	328782.117	4972679.418	26.845
206	328663.918	4972823.901	27.297
205	328610.469	4972764.860	28.336
204	328508.292	4972815.608	28.828
203	328512.992	4972911.766	27.662

APPENDIX E: OUTPUT CONTROL REPORTS

The following tables list the output control reports generated by TerraScan for the NVA points (**Table 13**) and the VVA points (**Table 15**). These tables list the Easting, Northing, Known (i.e. from GNSS RTK ground-truthing) Orthometric Height, Laser (i.e. from the drone survey) Orthometric Height, and the difference (D_z) between the Known and the Laser Orthometric Heights in metres (m) for NVA and VVA points, respectively. In both tables, an additional column was computed in Microsoft Excel using the values in the 'D_z' column. The newly created 'D_z (Abs)' column contains the absolute values of the height differences in the 'D_z' column.

Tables 14 and **16** contain summary accuracy statistics for NVA and VVA points respectively. One additional value was also calculated for each of these tables in Excel. The summary table for the NVA points (Table) contains a '95% Confidence' value, which was calculated by multiplying the 'Root Mean Square' value by 1.96. The summary table for the VVA points (Table) contains a 95th Percentile calculation, which uses the absolute D_z values in the 'D_z (Abs)' column from **Table 15**, and computes the number (i.e. the difference in height) that is greater than 95% of the D_z values of the VVA points.

Table 13: Output control report generated by TerraScan for the NVA points, and modified in Excel to add the column 'D_z (Abs)' and the '95% Confidence' value.

C:\ Lab3 \ RTK \ NVA_pxyz.csv						
Number	*Easting (m)*	*Northing (m)*	*Known Z (m)*	*Laser Z (m)*	*D_z (m)*	*D_z (Abs) (m)*
118	328631.079	4972836.763	27.489	27.460	-0.029	0.029
117	328683.237	4972704.668	27.865	27.840	-0.025	0.025
116	328703.557	4972656.107	27.574	27.500	-0.074	0.074
115	328728.544	4972592.256	27.100	*removed*	*	*
114	328702.908	4972557.771	27.085	27.010	-0.075	0.075
113	328700.451	4972526.112	27.141	27.060	-0.081	0.081
112	328694.645	4972460.396	26.623	26.560	-0.063	0.063
111	328723.160	4972403.856	26.487	26.410	-0.077	0.077
110	328749.111	4972514.847	26.732	26.680	-0.052	0.052
109	328800.873	4972498.535	26.313	26.270	-0.043	0.043
108	328878.750	4972473.444	26.316	26.200	-0.116	0.116
107	328853.459	4972419.116	25.980	25.880	-0.1	0.1
106	328790.772	4972435.331	26.846	26.810	-0.036	0.036
105	328763.233	4972383.064	26.236	26.160	-0.076	0.076
104	328720.882	4972323.928	25.606	25.500	-0.106	0.106
103	328746.915	4972297.341	25.309	25.220	-0.089	0.089
100	328832.891	4972251.754	24.739	24.650	-0.089	0.089

Table 14: Summarised accuracy statistics generated by TerraScan for the NVA points. Modified in Excel to calculate the '95% Confidence' value.

C:\ Lab3 \ RTK \ NVA_pxyz.csv	
Average D_z	-0.071
Minimum D_z	-0.116
Maximum D_z	-0.025
Average Magnitude	0.071
Root Mean Square	0.075
Standard Deviation	0.027
95% Confidence	0.147

Table 15: Output control report generated by TerraScan for the VVA points, and modified in Excel to add the column 'D_z (Abs)' and the '95th Percentile' value.

C:\ Lab3 \ RTK \ VVA_pxyz.csv						
Number	*Easting (m)*	*Northing (m)*	*Known Z (m)*	*Laser Z (m)*	*D_z (m)*	*D_z (Abs) (m)*
213	328902.122	4972450.809	25.517	*outside*	*	*
211	328665.410	4972420.072	27.757	27.770	0.013	0.013
210	328598.704	4972578.976	28.745	28.740	-0.005	0.005
209	328828.852	4972509.233	26.004	*removed*	*	*
208	328865.453	4972564.896	26.140	26.100	-0.04	0.04
207	328782.117	4972679.418	26.845	26.760	-0.085	0.085
206	328663.918	4972823.901	27.297	27.290	-0.007	0.007
205	328610.469	4972764.860	28.336	28.360	0.024	0.024
204	328508.292	4972815.608	28.828	28.790	-0.038	0.038
203	328512.992	4972911.766	27.662	27.680	0.018	0.018

Table 16: Summarised accuracy statistics generated by TerraScan for the VVA points. Modified in Excel to calculate the '95th Percentile' value.

C:\ Lab3 \ RTK \ VVA_pxyz.csv	
Average D_z	-0.015
Minimum D_z	-0.085
Maximum D_z	0.024
Average Magnitude	0.029
Root Mean Square	0.038
Standard Deviation	0.037
95th Percentile	0.070

APPENDIX F: PROJECT MAP

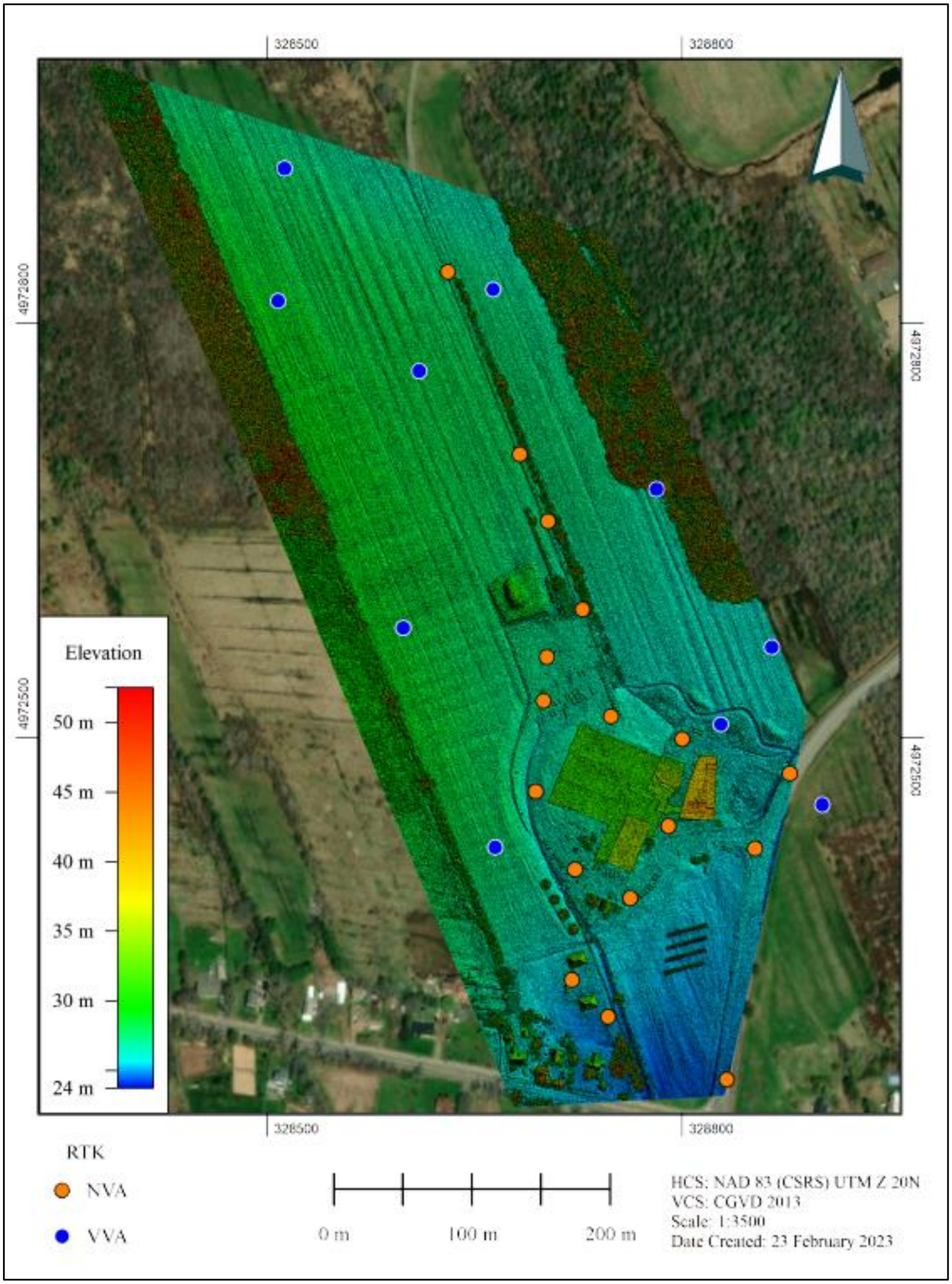


Figure 15: The project map showing the Full Earth surface (DSM) of the project area overlaying satellite imagery of the surrounding region. The locations of the NVA and VVA control points are also displayed.