The Use of Remote Sensing Technologies to Perform Tree Surveys

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SUMMARY

Use of Lidar Technology to Support Urban Forestry Resiliency

Developing local governments across the United States face the challenge of managing sustainable growth while preserving and valuating urban forest resources. For this reason, it is important to maintain an inventory or volume of the vegetation by conducting tree surveys, traditionally performed by land surveyors. To reduce the time and costs associated with performing conventional tree surveys, WGI, Inc. and WGI Geospatial's (collectively referred to herein as WGI) emerging technologies team developed a new process using topographic lidar mounted on an Unmanned Aerial System (UAS). Lidar sensors use millions of light pulses to capture a high-resolution, 3D image of all levels in the forest including the canopy, understory, and individual segments of trees. Lidar at close range is particularly adept at penetrating dense canopies to capture tree trunks and the ground with extreme precision. WGI's proprietary tree canopy workflow utilizes lidar point cloud technology to filter and segment the data into distinct tree stands. The individual trees are then subjected to a series of extraction processes to calculate important metrics, including diameter at breast height (DBH), canopy spread and height. The derived lidar data is then integrated into various geometric deliverables, such as crown height point data and tree canopy polygons, which can be conveniently compiled in an ESRI enterprise database. Field verification includes capturing the tree species identification, measuring, and confirming the trunk diameter at

breast height, 4.5 feet above ground level, (or as stated in the local tree ordinance) and capturing the metrics needed for any irregular shaped trees.

Use of innovative technologies and processes as discussed herein, can significantly reduce the time and cost of conventional tree inventory surveys performed for our clients within the land development, forestry and timber markets.

1. INTRODUCTION

Trees play a vital role in the health and social well-being of humans and to support sustainable communities. Forward thinking counties and municipalities throughout the world have established tree protection ordinances creating standards and guidelines to ensure the safeguard of heritage and protected trees and to provide a balance between tree preservation, tree removal and replanting during the commercial land development process. Land surveyors and other geospatial experts are tasked with performing tree surveys as a vital part of the land development process.

2. TREE CANOPY EXTRACTION PROCESSING WORKFLOW

To start a remote sensing project, it is important to first determine what type of data is needed and how it will be used. This information is critical to the planning process to determine how much area needs to be covered, how accurate the data needs to be, and what type of lidar sensor will be required.

The following workflow outlines the standard planning and processing steps for remote sensing point cloud data, with a focus on segmenting trees. When using lidar for forestry, it's especially important to have a good understanding of the project area. Factors like tree height, foliage density, undergrowth, and site-specific environmental conditions all play a crucial role in the project's success and the quality of data collected for further processing and extraction.

2.1 Flight Planning & Field Execution

The acquisition of lidar data is critical in the forestry industry and requires precision and accuracy to achieve the best results. For this use case, a DJI M600 Matrice with a TrueView 635 was utilized. This full electric medium lift platform is a lightweight lidar/camera fusion platform that houses a MiniVux-3UAV laser scanner and two 3DiS high accuracy image sensors that provide a 120-degree cross-track field of view.

The optimized flight plan parameters begin with a 55% side lap, which guarantees double coverage. An above-ground level (AGL) of 60m, an airspeed of 6 meters per second (m/s), a Pulse Rate Frequency (PRF) of 300 kHz, which resulted in an aggregate point density of +/- 305 ppm double coverage, and a laser spot size of 0.03m. This saturation of points, along with a reduced laser footprint, provides optimal look angles and range penetration for the sensor, increasing the chance of detecting and capturing the necessary information from various tree crown classes, particularly canopy branches that extend from the main trunk to form the uppermost layer of the canopy spread.

True View 635			
Flight Parameters	**Value**	**Units**	**Notes**
I plan to fly at this height (in meters)	60	m	Maximum effective altitude for True View 6xx is 100 m.
I plan to fly at this speed (in m/s)	5	m/s	Drone-dependent; recommend 5 m/s for typical projects.
I plan to have this total field-of-view (full angle, in degrees)	40	Degrees	Variable; recommend no greater then 90 degrees max, 80 degrees or less preferred.
I plan to have this %overlap (side)	50%	%	%overlap between adjacent flight lines.
I want to use this pulse repetion frequency (in KHz))	300	kHz	True View 6xx can be set to 100, 200, or 300 kHz.
I want to use this scan rate (Hz)	63.07	Hz	Scans 360 degrees. True View 6xx adjustable from 10 Hz - 100 Hz
... But the scan rate for uniform point spacing will be	*63.078*	*Hz*	See side note.
... I will need to set the angular step width to	*0.0757*	*degrees*	For uniform along/cross-track spacing.
... I will get this swath width on the ground	*100.69*	*m*	
... I will need to use this line-to-line spacing	*50.35*	*m*	See Line Spacing tab for Max Values
... I will get this average point density (single pass)	*152.64*	*pts/m²*	Sampling rate only, does not consider multiple retruns per pulse.
... I will get this average point density (overlap)	*305.28*	*pts/m²*	Sampling rate only, does not consider multiple retruns per pulse.
... I will get this point spacing (cross-track at nadir)	*7.93*	*cm*	Spacing at Nadir. Use the side note to calculate settings for uniform spacing.
... I will get this point spacing (along track at nadir)	*7.93*	*cm*	Spacing at Nadir. Use the side note to calculate settings for uniform spacing.
... I will have a spot size (cross-track at nadir)	*9.60*	*cm*	At Nadir
... I will have a spot size (along-track at nadir)	*3.0*	*cm*	At Nadir
System Parameters (From Manufacturer)	**Value**	**Units**	**Notes**
Pulse Repetition Frequency (PRF)	300.00	kHz	Sampling rate only, does not consider multiple returns per pulse.
Scan Rate	63.07	Hz	From above.
Beam Divergence (Cross-Track, full angle)	1.6	mrad	From manufacturer.
Beam Divergence (Along-Track, full angle)	0.5	mrad	From manufacturer.
#Channels	1	#	For multibeam/fan-type laser scanners
Operational Parameters (Calculated From Above Settings)	**Value**	**Units**	**Notes**
Altitude	60	m	From above.
Average Speed	5	m/s	From above.
Field of View (FOV) (Full)	40	Degrees	From above.
Effective Sampling Rate (ESR)	33.33	kHz	FOV/360*PRF
Swath Width	43.68	m	2*ALT*TAN(FOV/2)*PI/180
Swath Length	5	m	Average Speed
Swath Coverage	218.38	m²/s	Product of Above 2 Parameters
Average Point Density	152.64	pts/m²	ESR/Swath Coverage
Cross-Track Point Spacing	7.93	cm	Same as Per Channel calculation below.
Along-Track Line Spacing	7.93	cm	Same as All Channel calculation below.
Spot Size (Cross-Track)	9.60	cm	2*ALT*TAN((BD/2)/1000)*100
Spot Size (Along-Track)	3.00	cm	2*ALT*TAN((BD/2)/1000)*101
Per Channel Calculations			
PRF/Channel (kHz)	300.00	kHz	PRF/#Channels
Effective Sampling Rate (ESR) (kHz)(Per Channel)	33.33	kHz	FOV/360*(PRF Per Channel)
Average Point Density (pts/m²)(Per Channel)	152.64	pts/m²	(ESR Per Channel)/Swath Coverage
Angular Rate of Change Per Pulse (Per Channel)	0.076	deg/pulse	(360*SR)/(PRF/Channel)
Cross-Track Point Spacing (m)(Per Channel)	7.93	cm	ALT*TAN(ARC)*PI/180
Along-Track Line Spacing (m)(Per Channel)	7.93	cm	Speed/Scan Rate
Along-Track Line Spacing (m)(All Channels)	7.93	cm	Speed/Scan Rate/#Channels
Channel-To-Channel Seperation (m)	3.4	m	3.2 degree seperation on Ground from Altitude Specified
Scan Lag	42.28	#	#Scans Difference between Adjacent Channels Along-Track
Time Lag (s)	0.67	s	Time Difference between Adjacent Channels Along-Track

Figure 1: Use Case TrueView 635 Lidar Sensor Parameters

During lidar data acquisition, the system is coupled with a Trimble R-12 GNSS receiver, occupying a project control point established using the surrounding published 1st order vertical NGS control monument. This integration allows for increased accuracy and precision of the airborne data collected, ensuring that the airborne trajectory is of the highest quality.

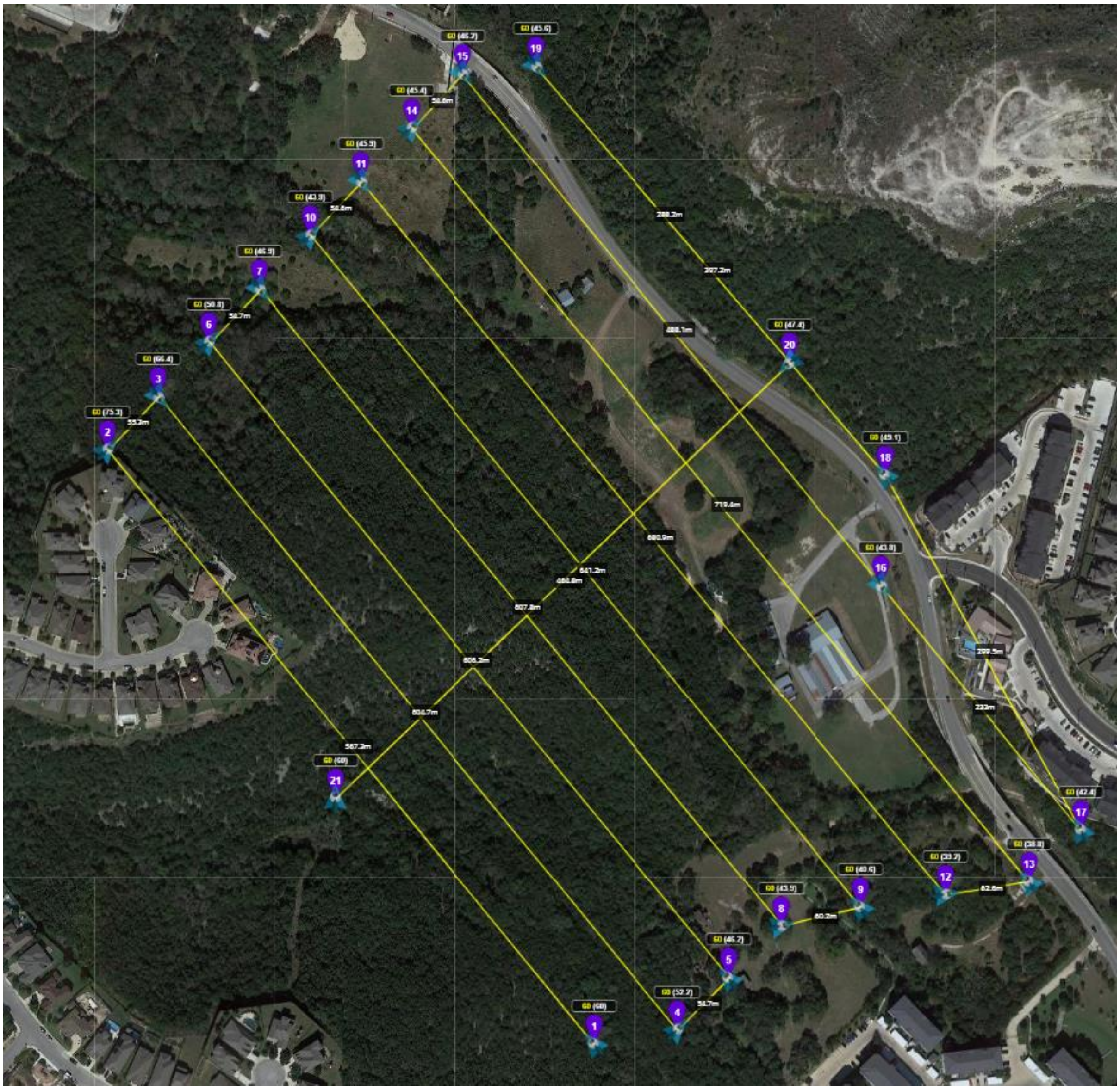


Figure 2: DJI M600 Matrice Flight Plan

2.2 Point Cloud Processing

An essential aspect of lidar-based forestry extraction is an effective point cloud processing workflow that aims to generate a geographically accurate point cloud dataset. This workflow involves several steps, starting with trajectory processing, which resolves the drone's geographic position in flight relative to the project area, utilizing a series of continually operating reference stations (CORS) or in this use case, bastion, to ensure survey-grade accuracy.

The next step is relative strip alignment, which computes and corrects relative roll, pitch, and yaw adjustments to fit each flight line to the next. The Z-debasement process follows, comparing the relative fit of the lidar corrected in the previous step to the collected survey control points, determining and applying a systematic adjustment to obtain the best fit solution between survey and the point cloud. The Standard Ground Classification applies a series of programmatic filters to determine the baseline ground. These initial stages help remove noise and correct errors in the data.

The next step involves vegetation filtering to separate vegetative and non-vegetative features, improving the accuracy of subsequent analyses and ensuring that only vegetation data is considered. The workflow then employs a grouping algorithm that enables individual segmentation of each tree in the dataset. This algorithm is based on a machine learning (ML) model developed by WGI that maps the patterns of existing trees in the collected dataset. After training the model with a 95% confidence level, it is applied to the entire project, and each individual tree stand is assigned a unique identifier. This identifier tags each point assigned to that group, and the information is embedded within the extra byte in the las file. This allows dynamic viewing of data not only by class but also by tree identification (ID). The advanced level of segmentation and filtering achieved through this process is critical in the forestry industry, enabling accurate and efficient analysis of critical tree characteristics, such as tree height, crown spread, crown height, and diameter at breast height (DBH). The unique identifier assigned to each tree stand provides a valuable reference for subsequent analysis and makes it easier to compare data across different datasets.

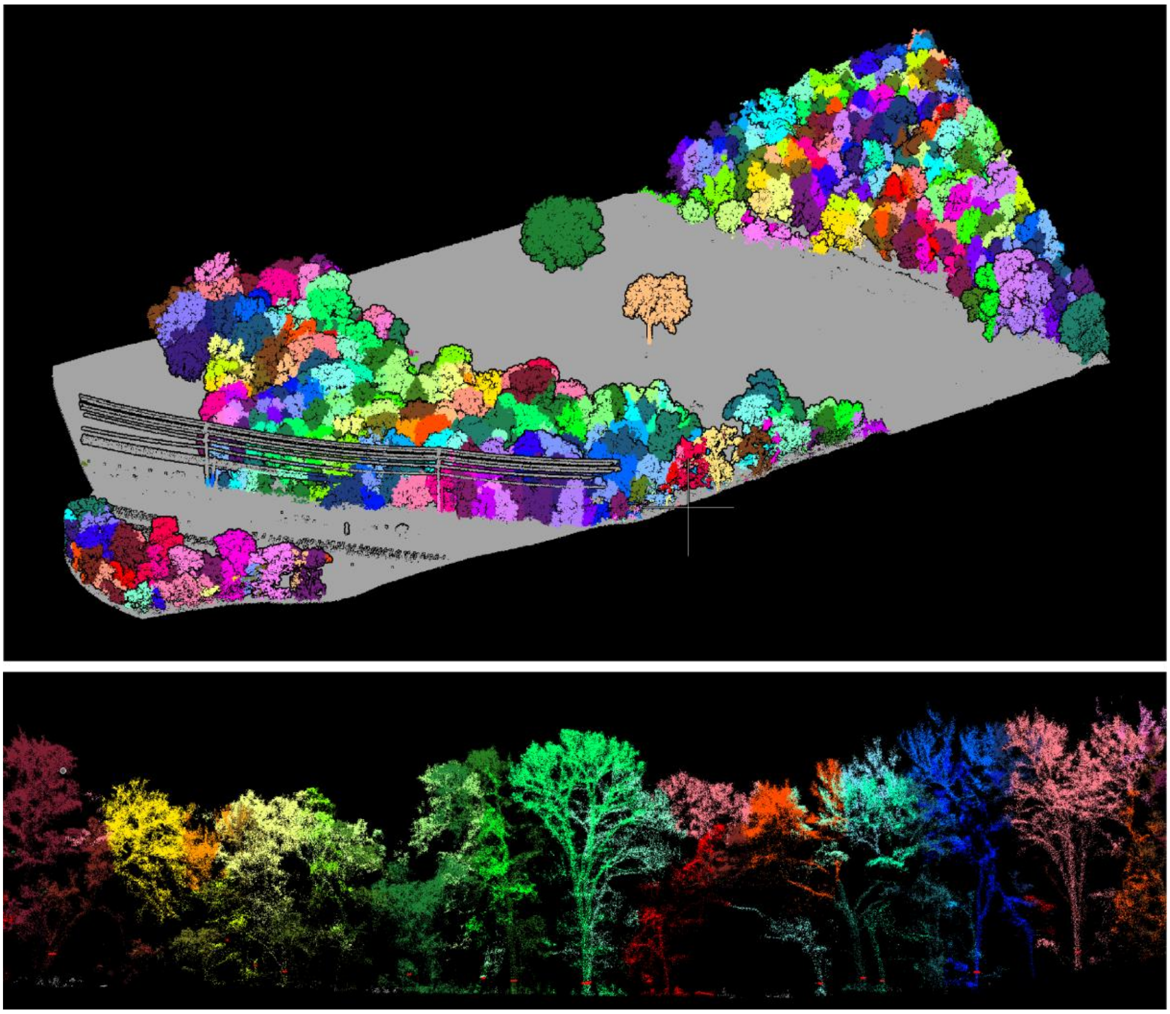


Figure 3: Tree Segmentation into Unique IDs

2.3 Data Extractions

After completing the point cloud classification and segmentation process, a programmatic analysis of forestry data is conducted. This analysis utilizes point cloud data contained within the unique tree ID to compute the aforementioned forestry metrics, such as tree height, crown width, crown height, and DBH trunk diameter. In the case of trunk diameter calculation, an algorithm is used that considers the ground elevation, the points within the specified tree ID, the measurement height (in this case, 4.5 feet), an estimated trunk diameter range, and a tolerance range of the best fit circle. If all the points fit within the given criteria, the trunk diameter is estimated with a high degree of accuracy. To compute the canopy spread area, the extents of the tree points connected to each ID are taken into consideration. Similarly, crown heights are computed based on the vertical distance from the base of the tree to the top of the tree's foliage or branches, rather than including the stem or trunk. The ability to differentiate between such subtle tree components ensures that the measurements obtained are highly accurate and reliable. It is worth noting that the accuracy and precision of the forestry analytics depend heavily on the quality of the point cloud data, as well as the appropriate filtering and segmentation of the individual tree stands. Therefore, it is crucial to use advanced techniques and algorithms to ensure the highest quality of results.

All forestry-related calculations are then exported in various customizable geometric and tabular forms, such as delineated polygons of the canopy spread and crown height centroid point features. This data is then stored in an ESRI enterprise database. The enterprise database feature layer is then hosted within WGI 's Arc Online Platform, allowing for easy access and sharing of the compiled forestry data, facilitating efficient decision-making and planning.

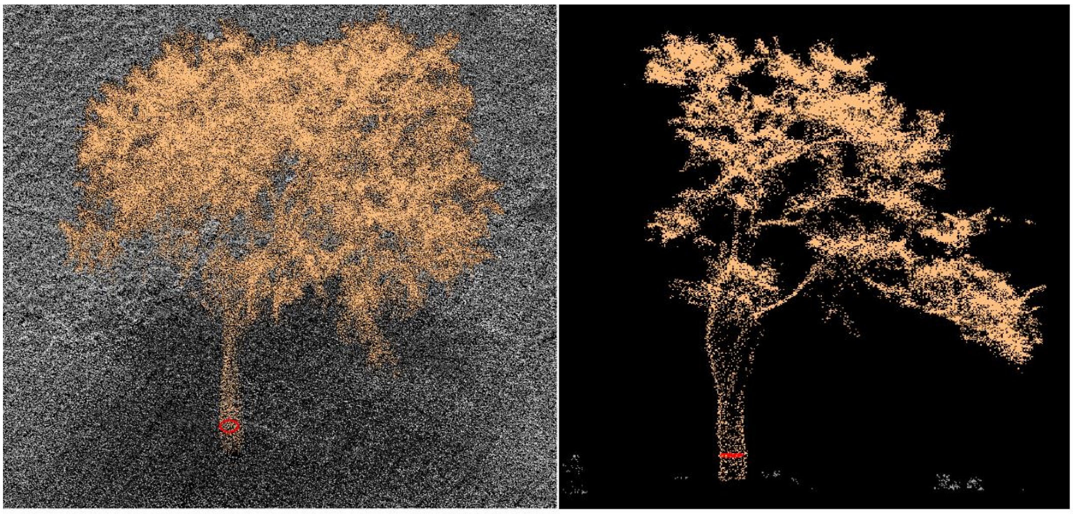
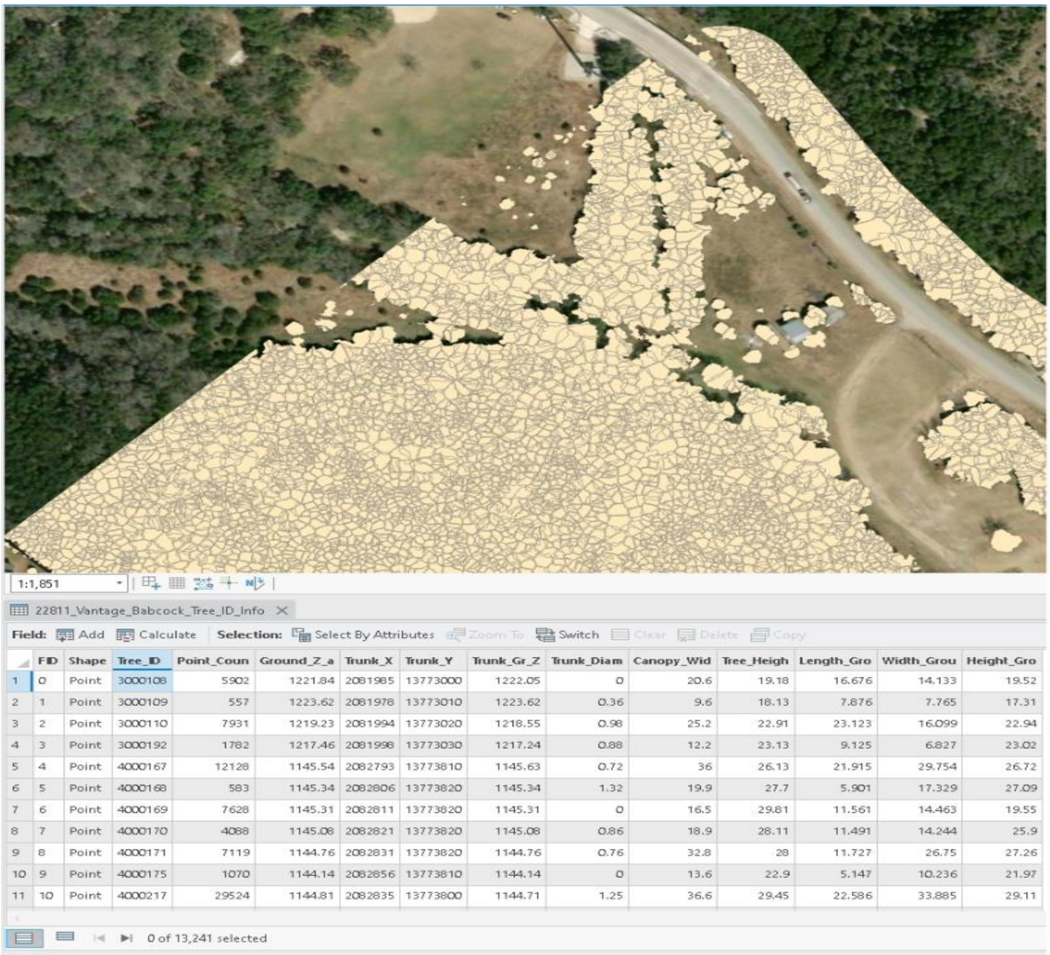


Figure 4: Programmatic DBH Extraction



	FID	Shape	Tree_ID	Point_Coun	Ground_Z_a	Trunk_X	Trunk_Y	Trunk_Gr_Z	Trunk_Diam	Canopy_Wid	Tree_Heigh	Length_Gro	Width_Grou	Height_Gro
1	0	Point	3000108	5902	1221.84	2081985	13773000	1222.05	0	20.6	19.18	16.676	14.133	19.52
2	1	Point	3000109	557	1223.62	2081978	13773010	1223.62	0.36	9.6	18.13	7.876	7.765	17.31
3	2	Point	3000110	7931	1219.23	2081994	13773020	1218.55	0.98	25.2	22.91	23.123	16.099	22.94
4	3	Point	3000192	1782	1217.46	2081998	13773030	1217.24	0.88	12.2	23.13	9.125	6.827	23.02
5	4	Point	4000167	12128	1145.54	2082793	13773810	1145.63	0.72	36	26.13	21.915	29.754	26.72
6	5	Point	4000168	583	1145.34	2082806	13773820	1145.34	1.32	19.9	27.7	5.901	17.329	27.09
7	6	Point	4000169	7628	1145.31	2082811	13773820	1145.31	0	16.5	29.81	11.561	14.463	19.55
8	7	Point	4000170	4088	1145.08	2082821	13773820	1145.08	0.86	18.9	28.11	11.491	14.244	25.9
9	8	Point	4000171	7119	1144.76	2082831	13773820	1144.76	0.76	32.8	28	11.727	26.75	27.26
10	9	Point	4000175	1070	1144.14	2082856	13773810	1144.14	0	13.6	22.9	5.147	10.236	21.97
11	10	Point	4000217	29524	1144.81	2082835	13773800	1144.71	1.25	36.6	29.45	22.586	33.885	29.11

Figure 5: Canopy Spread Geometry with Individual Tree Metrics

2.4 Field Validation

To bring data from the office to the field, WGI utilizes Esri workflows that allow for dynamic visualization of point and polygon features. Geometric extractions are compiled into an Esri enterprise database, which is hosted through the ArcGIS Online cloud or on-premises Esri portal interface for the user. For in-field validation, WGI uses ArcGIS Field Maps, an Android or IOS mobile application that allows the user to visualize and collect data within a customized web map environment and supplemental field data is collected using Trimble GNSS receivers and data collectors. These web maps display the point and polygon features containing calculated forestry metrics such as tree height and canopy spread, along with additional attributions specific to the field technician to check off on-site. Field technicians verify and update all programmatic results to ensure data accuracy and reliability.

During field validation, field technicians physically inspect trees and verify/review the attribute information displayed in the mobile app with real-world measurements and tree species determination. This process serves as an important quality control step to ensure data accuracy and identify potential errors that may have occurred during data collection or processing. WGI performs additional quality control measures to ensure that the tree inventory complies with the applicable tree ordinance and that the trees are classified per the ordinance.

After the field validation is complete, the data is prepared for additional analysis and interpretation. The collected data provides valuable insights into the structure and characteristics of the natural environment, especially in the forest industry. This data is used to identify and inform areas that require high-level management decisions in forestry operations.

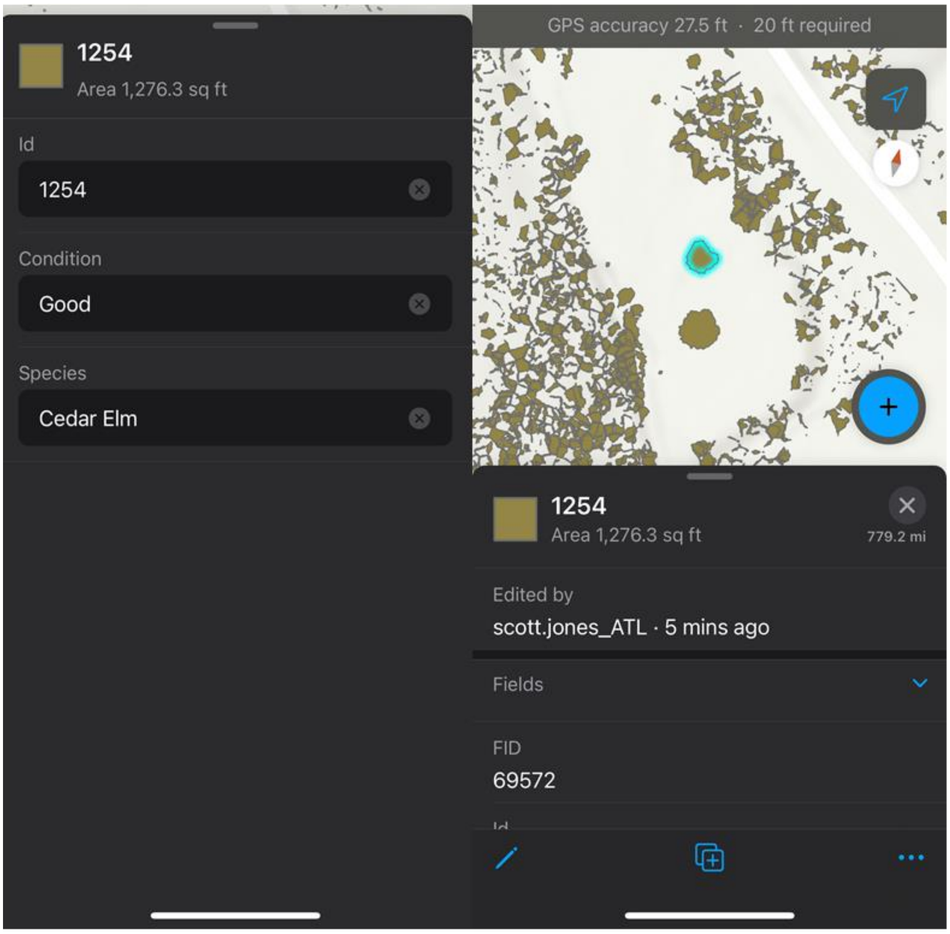


Figure 6: Example ArcGIS Field Maps Application

3. CONCLUSIONS

The use of aerial lidar and the extracted products/metrics, not only provide a significant reduction of time and cost in urban forestry surveys, but also offer additional insights on the individual tree stands. The process of digitizing and segmenting the forest as collected from an aerial perspective, allows for reliable data measurements of the trunk diameters (as traditionally required), and provides metrics on all vertical portions of the urban forest which allows for the possibility to perform biomass calculations, creation of canopy height models and tracking changes over time. Using advanced machine learning techniques in the segmentation and filtering of point cloud data is a significant development in the field of lidar technology. This approach enables more efficient and accurate extraction and analysis of data, providing valuable insights into the structure and characteristics of the natural environment. It revolutionizes the forest industry, reduces costly field time and provides additional diagnostic information to forest managers, conservation scientists, and other stakeholders.

Upcoming hardware additions to WGI's arsenal of remote sensing technology will include the implementation of a Near Infrared (NIR) image sensor, in addition to the existing RGB image sensors. The use of NIR imagery, also known as color infrared imagery, is a proven resource in forestry, aiding in the analysis of forest health, vegetation mapping and forest inventory due to the sensor's ability to detect reflective differences in the NIR wavelength between trees. WGI's ability to fuse both NIR and RGB pixels with the lidar point cloud adds another layer of data information that can be quantified and extracted by forestry professionals.

As WGI looks to the future of the use of remote sensing in forestry applications, the company has begun integrating virtual reality (VR) technology. The use of augmented reality (AR) and VR within the geospatial industry has accelerated in the past few years, and WGI Geospatial has been at the forefront of innovative practices. WGI has teamed up with AKULAR to integrate point cloud datasets that allow for virtual field validation. Analysts will soon be able to analyze individual trees from the safety and comfort of their office by virtually sailing through the dataset.

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BIOGRAPHICAL NOTES

Coleen Johnson is Market Leader, Transportation for the Geospatial Division of WGI, Inc. in Austin, Texas. She is a Registered Professional Land Surveyor (RPLS) in Texas with over 35 years of experience in the geospatial industry. She is a member and Past President of the Texas Society of Professional Surveyors (TSPS), a member of the National Society of Professional Surveyors (NSPS), a member of the National Council of Examiners for Engineering and Land Surveying (NCEES) Examinations for Professional Surveyors (EPS)

Committee, and a RPLS board member of the Texas Board of Professional Engineers and Land Surveyors.

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