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FALL 2025

MAGAZINE

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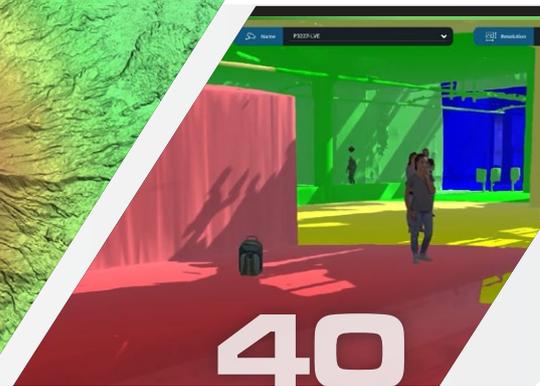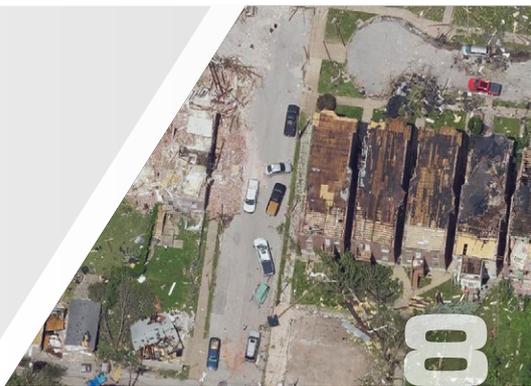
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8

10

40

IN THIS ISSUE

DEPARTMENTS

COLUMNS

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◄ **ON THE COVER**
Imagery-based 3D model of the National Museum of the United States Air Force, Dayton, Ohio. Image courtesy of Woolpert and the United States Air Force.

Lidar Flies above Uncertainty

As 2025 draws to a close, we can look back on a fascinating year—and look forward to the continuance of current trends.

One of the frustrations of editing *LIDAR Magazine* is that every week in life there's an enticing trade show or conference at which more could be learned about lidar innovations, but it's possible to attend only a few of them. Nevertheless, it's a privilege to have attended Topographic Mapping from Space dedicated to Dr. Karsten Jacobsen's 80th birthday in Istanbul, Geo Week in Denver, 59th Photogrammetric Week in Stuttgart, ISPRS Geospatial Week 2025 in Dubai, Hexagon LIVE Global 2025 in Las Vegas, Esri International User Conference in San Diego, Fifteenth Session of UN-GGIM in New York, Intergeo in Frankfurt, and Latin America GRSS and ISPRS Remote Sensing Conference (LAGIRS 2025) in Foz do Iguaçu. These events were very different. Some were research-oriented, the ISPRS-related ones being focused on PhD students and early-career researchers presenting their work. They reinforced the huge importance being attached to AI and the strides being made in extracting useful information from lidar data, though we must remember that researchers also provide useful information on the performance of both experimental and off-the-shelf hardware and software. They were reminders, too, of the surprising range of application areas where lidar is playing an important role—socioeconomic analyses of cities in Brazil was an unexpected one reported at LAGIRS. UN-GGIM was more policy-focused, but reminded attendees how lidar is a key component in the geospatial arsenal being brought to bear in pursuit of the elusive SDGs. The others were more commercial, conduits for the launches and exploration of remarkable hardware and software.

Reports from many of these events have been posted on www.lidarmag.com. Probably the most useful was Intergeo. Not only is it an enormous event, perennially chosen by suppliers to launch new products, but it included excellent panel discussions. While there was no hiding from ongoing geopolitical uncertainty and the economic woes hovering in its wake, there was optimism about geospatial technology and its benefits. Again, AI was on most people's lips, as was processing of gigantic volumes of data, usually in the cloud. A critical implication, however, is that the use of all these developments hinges on a workforce with different skills from those of today. For example, using an instrument in the field remains important, but it's easier than it used to be. Judging whether AI results are sensible is a different matter. "Soft skills" are more useful than heretofore.

We will look back on 2025 as one in which there were major developments on the airborne side. The Sony IMX811 247-megapixel

CMOS chip, for example, has rapidly been incorporated in many airborne sensors. Hybrid sensors generating both imagery and lidar are here to stay. Topographic and topobathymetric lidar sensors offer more performance. Scan patterns seem more significant, and a geospatial services company may select a sensor because it offers a scan pattern well suited to the requirements of its end market. A recurring theme is the demand for fast, less expensive deployment, for example to meet the needs of first responders, provoking development of smaller, lighter systems suitable for use on helicopters or lighter aircraft, often in pods, as well as UAV-photogrammetry and UAV-lidar innovations. US regulations have resulted in different UAV market conditions compared to other G20 countries, but this has been healthy in the sense that the demand for NDAA-compliant solutions has encouraged integrations that would not otherwise have occurred. Nevertheless, in situations where NDAA is not the prime driver, the announcement of certain platforms has resulted in the refinement of sensors developed to suit.

Some of these trends are reflected in this issue's articles. Brett Thomassie of Bowman discusses the importance of fast deployment and data production for first response, search and rescue and mitigation after events, such as hurricanes, which are increasing in frequency and intensity. Bret Burghdurf of GeoCue describes a practical example of laser scanning of schools in a Louisiana parish, generating deliverables tuned very carefully to the requirements of first responders and their dispatchers.

The piece by Martin Vojtek of Hexagon underlines the point about the breadth of applications. Martin joined Hexagon through its acquisition of Accur8vision in 2020, an early response to the fast-growing market for 3D lidar-based surveillance. The client in this case is an electrical utility.

There are two deeper articles. Contributing writer Qassim Abdullah provides further detail on the ASPRS *Positional Accuracy Standards for Digital Geospatial Data*, in this case the 3D components. Geospatial standards are typically separated into planimetry and elevation, but they can be combined. The underlying principles, however, are the same as for the other standards in the set, which have been the subject of earlier articles.

We are delighted to provide the fourth and final part of Gottfried Mandlburger's tutorial series on "Airborne Lidar—A Tutorial for 2025." This one is on UAV-lidar, so it's timely in view of the unmistakable energy in this area at Intergeo.

A second contributing writer and Woolpert leader, Amar Nayegandhi, brings another of his *Full Coverage* columns to end this issue. We don't try to influence Amar's choice of topics, so it's serendipitous that he has chosen geospatial data for hurricane response and resilience. Naturally, several of his points echo those of Brett Thomassie and, in turn, those made by panelists at Intergeo about fast deployment and processing.

Thanks to these authors, *LIDAR Magazine* has been able to offer material to substantiate industry trends. That is indeed be one of our roles, so it is satisfying to conclude the year with some success. It's reassuring, too, that the US geospatial industry has resources and management expertise on hand to respond to the exigencies occasioned by the forces of nature.

We also have a book review of *It Is Your Game* by well-known lidar and imagery veteran and EAASI vice president, Simon Musaeus. The book is a compendium of business management techniques that can be used to develop and refine strategy. It's relevant to many small- and medium-sized geospatial businesses, of course, and one of its strengths is a chapter written for the manager who knows that things have to change but is on the verge of panic and doubts he has time to think about strategy. Of course, none of us has been there…

It Is Your Game is intense, requiring conscientious study. Simon has not put his keyboard aside, however, and has provided me recently with a manuscript of another book, this time a "business novel," albeit based on a real case. It's co-authored by Frank Zijlstra and has the engaging title *From Chaos to Exit.*

All our authors, therefore, are acknowledged industry heavyweights. This is an apposite moment, moreover, to mention the *LIDAR Magazine Podcast Series* and record our gratitude to guests in this endeavor for preparing and giving their views. By the end of the year we will have made 28 podcasts, 14 in 2024 and 14 in 2025. The guests exemplify one of the characteristics of our geospatial community: it brims with talented, energetic individuals, many of them entrepreneurial, and it's an honor to work in this milieu. The new technologies announced with fanfare in 2025 will be deployed in 2026 and beyond. Lidar will remain center-stage.

Thank you, readers, for accompanying us in 2025. We look forward to sharing more with you in 2026.

A. Stewart Walker // Managing Editor
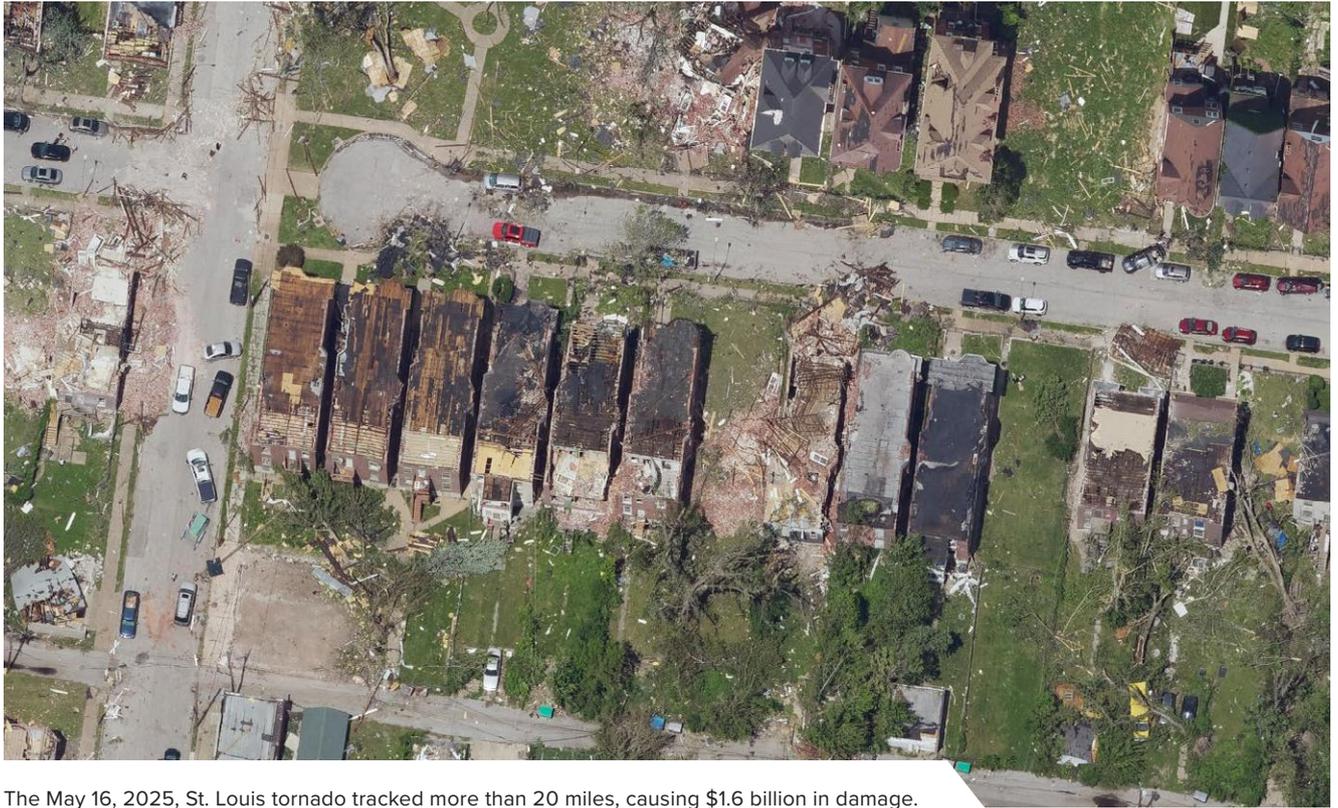
The May 16, 2025, St. Louis tornado tracked more than 20 miles, causing $1.6 billion in damage.

Five Keys to Faster, Smarter Disaster Response Mapping

A field-tested framework for accelerating disaster response

Natural disasters in the United States are occurring more often and hitting harder. The number of weather events causing at least $1 billion in damage has more than doubled in the past decade. And it's not just about cost: in recovery, rapid response time is critical, starting with accurate, up-to-date, early-access aerial orthoimagery to support first responders and the disaster remediation process.

Following the May 16, 2025, St. Louis tornado, which damaged more than 5000 buildings and displaced thousands, Bowman's aerial imaging crews were immediately deployed and imagery acquisition was underway within 24 hours. Three-inch resolution imagery was captured across 75 square miles, giving emergency crews a complete view of the damage. Instead of relying on scattered reports, response teams were able to assess conditions quickly and act on verified information.

BY BRETT **THOMASSIE**

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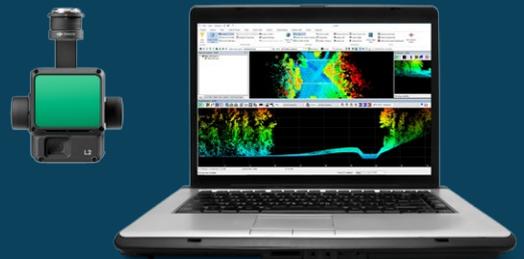
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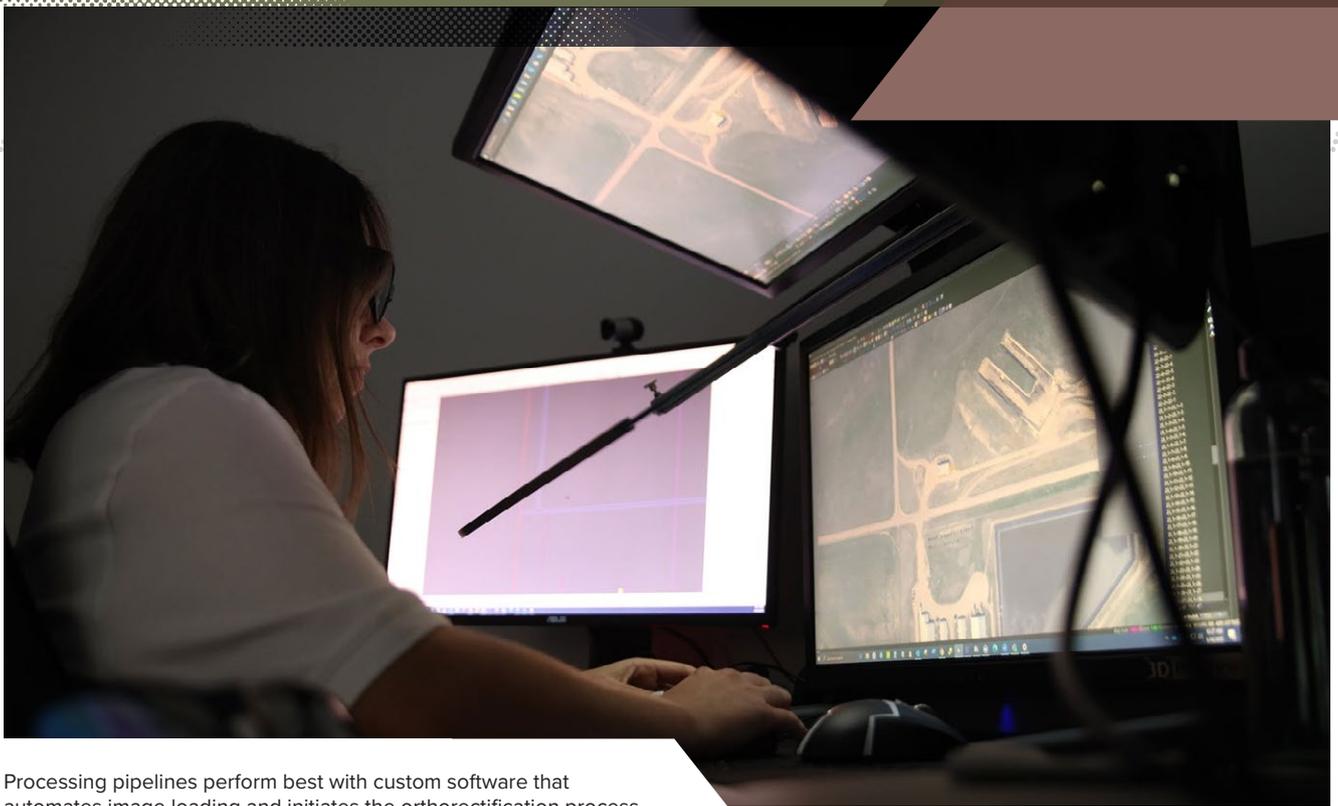
Processing pipelines perform best with custom software that automates image loading and initiates the orthorectification process.

This rapid timescale matters. After supporting disaster mapping across the U.S. in recent years, Bowman has found that five technical components must work together to make rapid response possible.

Fast aircraft

Disaster mapping relies on the performance and endurance of the aircraft, making quick mobilization essential. An aircraft with the ability to cruise at 300 knots and stay aloft for up to seven hours on a single tank of fuel is ideal. These aircraft and Bowman's centrally located hangar in the St. Louis, Missouri area allow for rapid deployment to any location in the continental U.S. within a few hours and extended flight times once on-station, maximizing the area that can be captured in a single mission. Coordinating directly with air traffic control and military/restricted airspace installations is also key. This ensures efficient flight paths over impacted areas, and real-time telemetry lets ground crews track progress and adjust plans as conditions change.

Large format sensors

Leica ADS100 large format push-broom and Phase One PAS PANA frame digital image sensors offer some of the widest swath widths and large-area coverage available on the market today. This wide coverage means fewer passes are needed to capture the same area, reducing both flight time and data volume. Push-broom technology also produces significantly fewer seamlines than frame cameras, which translate directly to less image processing time. The state-of-the-art PAS PANA frame cameras were developed by Phase One in coordination with Bowman specifically for large area collections such as the requirement to collect entire U.S. states for the USDA National Agriculture Imagery Program (NAIP).

The airborne GNSS receivers and IMUs that are flown with these large-area coverage sensors deliver highly accurate positional data that minimizes the need for extensive ground control, further accelerating orthorectification. The result is accurate, consistent imagery that moves quickly from capture to processing.

Rapid image generation

Fast data collection is important—but transforming that data rapidly into actionable information truly makes the difference. High-performance processing pipelines perform best with custom software designed for Leica ADS100 and Phase One PAS PANA data. Specifically, Bowman has developed software that automates image loading from the field and initiates the ortho-rectification process without manual intervention.

In recent operations, Bowman implemented a parallel-processing framework capable of processing thousands of square miles of imagery within a few hours. This can then be uploaded to an online web service for early-access consumption, dramatically reducing the time required for the data to reach first responders before the final orthorectification processing

cycle. While this initial, early-access imagery lacks some of the refinements of fully processed orthoimagery, it strikes the ideal balance between the speed and accuracy necessary for rapid-response disaster mapping.

AI-powered workflows

AI is speeding up one of the most time-consuming steps of disaster mapping—turning raw imagery into useable data. Machine-learning models trained on thousands of disaster scenarios can quickly scan imagery to classify structurally damaged ground features, detect downed power lines, identify impassable roads and estimate debris volumes.

Object-detection algorithms go even further by extracting features and delivering them as GIS-ready shapefiles and geodatabases ready for immediate use and integration into emergency platforms. At the same time, AI will double-check its own work by scanning for misalignments, seamline artifacts or classification errors that could slow down response efforts. By automating both analysis and quality control, the system ensures data meets operational standards without delays—turning what used to be a manual, hours-long review into a matter of minutes.

Accessible display service

Even the best imagery is useful only if it's accessible. Online-display web services are best, allowing processed imagery datasets to be available within 24-48 hours of acquisition—well ahead of the delivery of final orthorectified imagery. The display service should run on any web browser without plug-ins and be accessible on desktop and mobile devices.

For high-demand situations, it's recommended that imagery be mirrored across multiple platforms, such as Esri and other web services, to ensure uninterrupted access.

When these five components—fast aircraft, large-format sensors, rapid data generation, AI-driven workflows and accessible display services—come together, they deliver actionable intelligence within hours of a disaster. Speed transforms response: search and rescue teams pinpoint their efforts, utilities restore critical infrastructure faster and communities move from chaos to recovery without delay. ▪

Brett Thomassie brings more than 30 years of experience working with satellite and aerial imagery, delivering fast, accurate maps when timing is critical, for example, after disasters or for vital infrastructure and defense work. He has led geospatial teams leveraging both aircraft and satellite platforms and built lasting relationships with government agencies such as USDA, USGS, NOAA and USACE. His background includes government geospatial data sales/business development, remote sensing, cartography and program management.

Bowman

Bowman is one of the most advanced mapping firms in the US, operating a fleet of crewed and unmanned aircraft to deliver high- and low-altitude geospatial solutions for both public and private sector clients. Its aerial data supports applications from infrastructure planning and environmental studies to disaster response, serving long-term customers such as state departments of transportation, USDA, USGS and USACE.

These capabilities expanded significantly in April 2024 with the acquisition of Surdex Corporation[1], a longtime industry leader based in St. Louis, Missouri. The addition of Surdex strengthens Bowman's ability to provide high-resolution imagery, lidar and mapping products. With this integration, the legacy built by Surdex over decades continues—now as part of Bowman.

Henceforward, orthoimagery coverage and knowledge will come under the Bowman name, now backed by the technical leaders of Surdex whom readers have learned to trust.

Geospatial work is just one part of what Bowman does. The company is a national engineering services firm delivering infrastructure, technology and project management solutions to those who own, develop and maintain the built environment. With 2500 employees across 100 locations, Bowman offers planning, engineering, construction management, commissioning, land procurement and environmental consulting services to customers operating in a diverse set of regulated end-markets.

Bowman trades on the Nasdaq under the symbol BWMN, with its second quarter 2025 earnings marking another period of rapid growth and strategic progress.

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1   https://investors.bowman.com/news/news-details/2024/Bowman-Enters-into-Definitive-Agreement-to-Acquire-Surdex-Corporation-Adding-High-Altitude-Digital-Imagery-Digital-Mapping-and-Advanced-Geospatial-Services/default.aspx
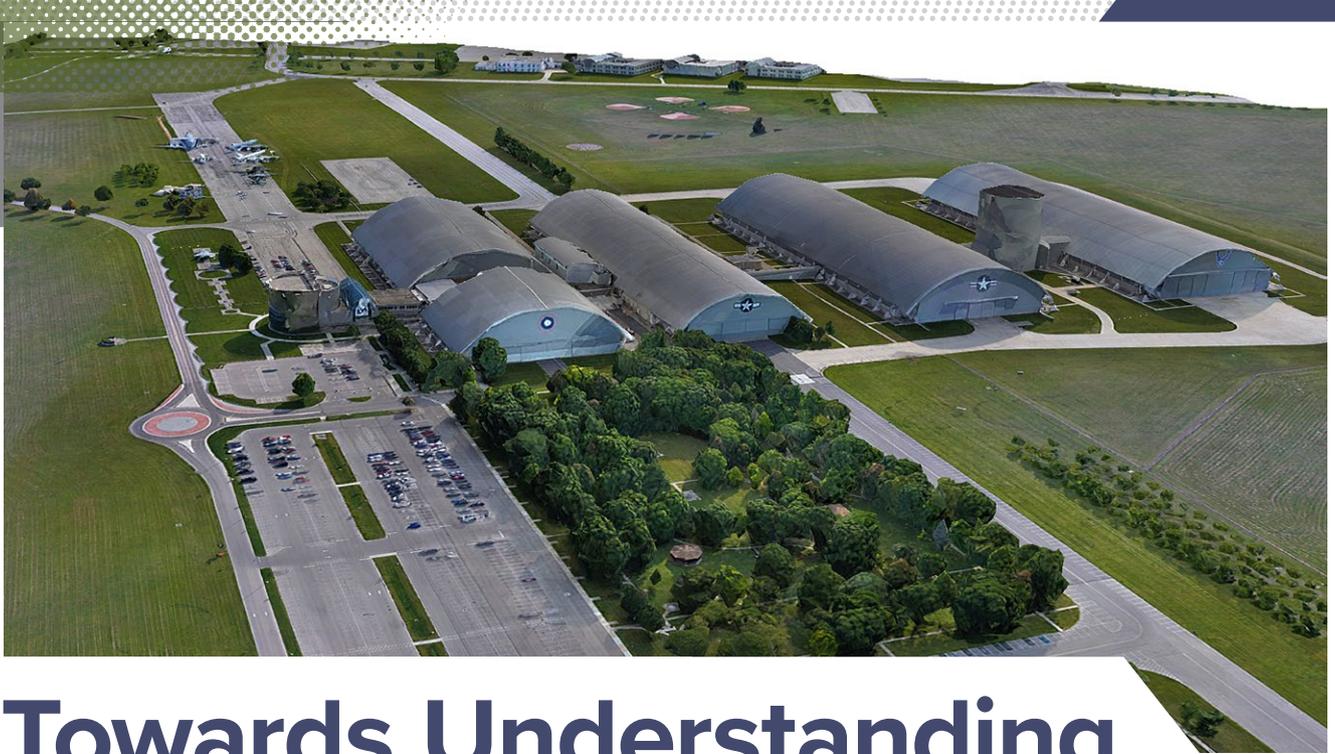
Towards Understanding the New Three-Dimensional Accuracy of the ASPRS Accuracy Standards

BY QASSIM **ABDULLAH**

With the geospatial industry increasingly moving towards three-dimensional GIS and true three-dimensional representation of terrain and infrastructure, it becomes prudent for mapping standards to provide a measure to assess the accuracy of such representations. This measure was defined in the latest American Society for Photogrammetry and Remote Sensing (ASPRS) *Positional Accuracy Standards for Digital Geospatial Data*, published in 2024,

in which the term "three-dimensional accuracy" was introduced to complement horizontal and vertical accuracy terms. This article provides users of the standards with practical methods for assessing the three-dimensional accuracy of geospatial data and helps them understand this new term of accuracy.

Our world in 3D and the challenges in representing it

Whether from space or aerial platforms, advances in lidar, radar, and other

mapping and surveying sensors and instruments enable us to view the world in true 3D—revealing what we have never seen before. GIS, environmental, and engineering applications are becoming heavily dependent on 3D point clouds and 3D modeling (see **Figures 1 through 3**). Similarly, new applications like digital twins, BIM, and smart cities push the demands for 3D data to a new level.

Despite the high demand for 3D data, the industry is still behind in dealing with such data in a true 3D environment. We are still evaluating horizontal and vertical accuracy separately owing to

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the lack of effective tools for visualizing and performing measurements in 3D. Even the most widely used GIS and CAD tools in the industry do not provide such capabilities. What badly need software manufacturers to create a tool that presents 3D models or point clouds in true 3D and provides a terrain-following cursor for 3D measurement capabilities.

The new 3D positional accuracy

The ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) provides the following justification for introducing the new third term of positional accuracy: "Three-dimensional models and digital twins are gaining acceptance in many engineering and planning applications. Many future geospatial datasets will be in true three-dimensional form; therefore, a method for assessing positional accuracy of a point or feature within the 3D model is needed to support future innovation and product specifications.[1]"

According to the standards, the accuracy of the 3D position (X, Y, and Z) of features, with respect to horizontal and vertical datums, is computed using the following formula:

$$RMSE_{3D} = \sqrt{RMSE_X{}^2 + RMSE_Y{}^2 + RMSE_Z{}^2}$$

The $RMSE_X$, $RMSE_Y$, and $RMSE_Z$ of the checkpoints are computed by comparing the coordinates obtained from the map or 3D model to the surveyed coordinates of the checkpoints.

Suggested strategy to quantify the 3D accuracy

The following are scenarios that users

1   publicdocuments.asprs.org/PositionalAccuracyStd-Ed2-V2, page 8.
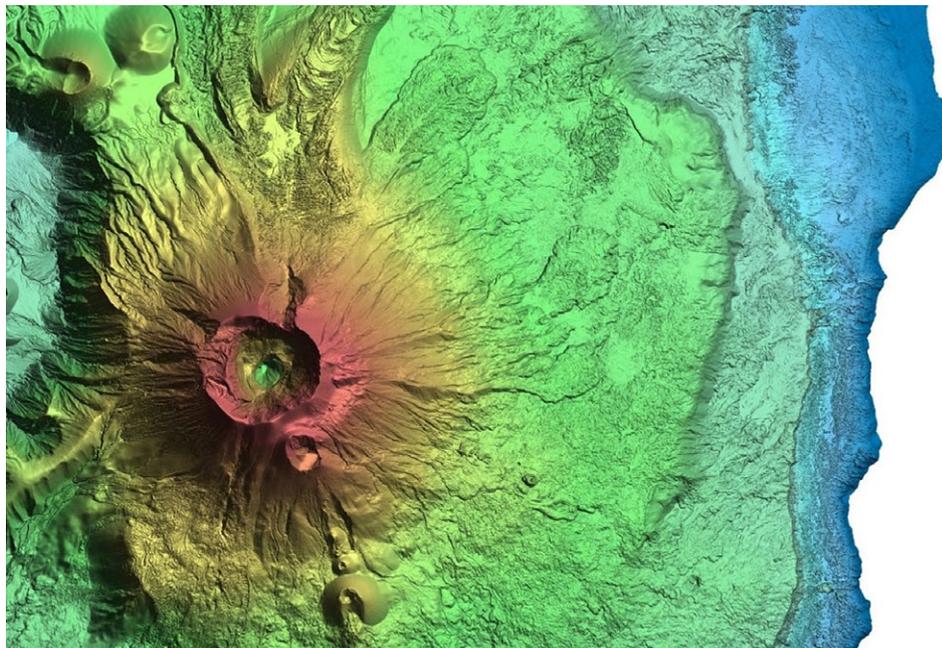
Figure 1: Lidar model of a volcano site in Hawaii
Courtesy of Woolpert and USGS

may encounter when assessing 3D positional accuracy:

1. Using checkpoints that are suitable for vertical and horizontal accuracy assessment

These checkpoints are usually referred to as photo-identifiable checkpoints. Users can easily identify and accurately measure these points in imagery or lidar intensity images. They can be paneled targets suitable for imagery or lidar, or existing features in the scene, such as road stripes, parking-space stripes, or corners of utility manholes. Such checkpoints are typically used for photogrammetry, but can also be utilized to assess lidar accuracy. They enable true 3D measurement capabilities if the appropriate software exists. For photogrammetry, a stereoplotter can assess 3D accuracy in a true 3D environment. For lidar data, due to the lack of 3D-enabled software that supports true 3D measurements, horizontal and vertical accuracy can be assessed

separately and then combined using the formula provided to compute the 3D accuracy. **Table 1** represents an accuracy computation according to the new ASPRS standards, where all components of horizontal and vertical accuracy exist.

For the accuracy assessment session presented in **Table 1**, it is assumed that the checkpoints were surveyed using standard RTK-based GNSS surveying practice, where the survey accuracy is assumed to be around 2.0 centimeters (or 0.066 feet) horizontally and vertically. Knowledge about survey accuracy is required to compute the final product accuracy according to the new standards.

The first component of errors in **Table 1** is computed from the product fit to the checkpoints provided in the three rightmost columns:

$$RMSE_{3D_1} = \sqrt{RMSE_X{}^2 + RMSE_Y{}^2 + RMSE_Z{}^2}$$

Or:

$$RMSE_{3D_1} = \sqrt{0.553^2 + 0.590^2 + 0.254^2} = 0.848 \text{ ft.}$$

Table 1: Geospatial product accuracy computations example

Point #	Surveyed Coordinates			Map Coordinates			Error Values (ft.)		
	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Error in Easting (ft.)	Error in Northing (ft.)	Error in Elevation (ft.)
CP_1	2447813.666	320999.277	1091.290	2447813.745	320999.886	1091.041	-0.079	-0.609	0.249
CP_2	2447783.731	321113.799	1095.153	2447783.872	321114.131	1094.945	-0.141	-0.333	0.208
CP_3	2447759.165	321215.297	1098.398	2447759.805	321216.064	1098.148	-0.640	-0.767	0.250
CP_4	2447733.079	321308.624	1101.503	2447734.077	321309.328	1101.232	-0.997	-0.704	0.271
CP_5	2447700.757	321419.045	1105.196	2447701.039	321419.393	1104.925	-0.282	-0.348	0.272
CP_6	2447674.817	321511.857	1108.295	2447675.068	321512.646	1108.004	-0.251	-0.789	0.291
CP_7	2447653.663	321604.458	1111.250	2447653.973	321604.580	1110.852	-0.310	-0.122	0.398
CP_8	2447626.292	321705.399	1114.654	2447627.196	321706.205	1114.357	-0.904	-0.807	0.297
CP_9	2447596.353	321793.142	1117.680	2447596.445	321793.785	1117.340	-0.091	-0.642	0.339
CP_10	2447571.460	321890.393	1120.912	2447571.985	321890.750	1120.860	-0.524	-0.357	0.053
CP_11	2447546.661	321995.976	1124.451	2447547.164	321996.487	1124.188	-0.503	-0.511	0.263
CP_12	2447526.557	322083.359	1127.236	2447526.923	322083.384	1126.979	-0.366	-0.025	0.257
CP_13	2447500.261	322166.601	1130.190	2447501.255	322167.463	1129.896	-0.994	-0.862	0.294
CP_14	2447466.423	322281.229	1134.034	2447467.060	322282.134	1133.836	-0.637	-0.905	0.198
CP_15	2447308.665	322248.522	1138.270	2447308.853	322248.748	1138.075	-0.188	-0.226	0.195
CP_16	2447344.717	322148.450	1134.550	2447344.809	322148.749	1134.343	-0.092	-0.299	0.207
CP_17	2447365.379	322069.094	1131.729	2447366.118	322069.380	1131.606	-0.739	-0.286	0.124
CP_18	2447397.698	321961.434	1127.951	2447397.923	321961.772	1127.802	-0.225	-0.338	0.149
CP_19	2447432.470	321852.655	1124.165	2447432.820	321853.379	1124.070	-0.351	-0.724	0.095
CP_20	2447461.110	321756.112	1120.759	2447461.289	321756.306	1120.491	-0.178	-0.193	0.268
CP_21	2447488.289	321668.755	1117.655	2447488.705	321669.220	1117.306	-0.416	-0.464	0.349
CP_22	2447517.838	321559.055	1113.819	2447518.485	321559.832	1113.544	-0.648	-0.777	0.275
CP_23	2447551.427	321449.022	1110.043	2447552.148	321449.791	1109.801	-0.721	-0.769	0.242
CP_24	2447574.256	321367.151	1107.080	2447574.808	321368.040	1106.854	-0.551	-0.889	0.226
CP_25	2447603.184	321268.437	1103.592	2447603.749	321268.847	1103.287	-0.565	-0.410	0.306
CP_26	2447630.643	321182.130	1100.562	2447631.516	321183.004	1100.299	-0.873	-0.874	0.263
CP_27	2447746.661	322195.976	1126.451	2447747.164	322196.487	1126.188	-0.503	-0.511	0.263
CP_28	2447956.698	322520.434	1129.951	2447956.923	322520.772	1129.802	-0.225	-0.338	0.149
CP_29	2447658.148	321084.483	1097.144	2447658.603	321085.080	1096.927	-0.455	-0.597	0.217
CP_30	2447691.264	320973.009	1093.237	2447692.172	320973.591	1092.907	-0.909	-0.582	0.330
Number of Check Points							30	30	30
Minimum Error							-0.997	-0.905	0.053
Maximum Error							-0.079	-0.025	0.398
Mean Error							-0.479	-0.535	0.243
Median Error							-0.479	-0.547	0.260
Standard Deviation							0.282	0.252	0.076
RMSE							0.553	0.590	0.254
First Component of Horizontal Positional Accuracy RMSE$_{H1}$							0.809		
First Component of Vertical Positional Accuracy RMSE$_{V1}$							0.254		
Enter Survey Horizontal Accuracy RMSE$_{H2}$							0.066		
Enter Survey Vertical Accuracy RMSE$_{V2}$							0.066		
Final Product Horizontal Positional Accuracy RMSE$_{H}$							0.811		
Final Product Vertical Positional Accuracy RMSE$_{V}$							0.263		
Final Product Three-dimensional Positional Accuracy RMSE$_{3D}$							0.853		

Figure 2: 3D model of an industrial complex
Courtesy of Woolpert

The second component of positional error is the error in the survey of the checkpoints:

$$RMSE_{3D_2} = \sqrt{RMSE_{Hsurvey}^2 + RMSE_{Vsurvey}^2}$$

Or:

$$RMSE_{3D_2} = \sqrt{0.066^2 + 0.066^2} = 0.093 \text{ ft.}$$

The final 3D product accuracy is computed as follows:

$$RMSE_{3D} = \sqrt{RMSE_{3D1}^2 + RMSE_{3D2}^2} = 0.853 \text{ ft.}$$

2. Using checkpoints that are suitable for only vertical or horizontal accuracy assessment.

In the lidar industry, checkpoints are usually acquired to assess vertical accuracy. Horizontal accuracy of lidar data is rarely assessed by users. Checkpoints suitable for assessing vertical accuracy may not be suitable for assessing horizontal accuracy, as they are often not identifiable in the intensity image. In this scenario, however, we will assume that vertical and horizontal accuracy are assessed using separate sets of checkpoints. The accuracy assessment in this case is straightforward: vertical accuracy is assessed separately from horizontal accuracy and they are then combined to compute the final 3D accuracy. Assuming the final horizontal accuracy ($RMSE_H$) is computed, from **Table 1**, to be 0.811 feet, and the final vertical accuracy ($RMSE_V$) is found to be 0.263 feet, the 3D accuracy is computed as follows:

$$RMSE_{3D} = \sqrt{RMSE_H^2 + RMSE_V^2} = \sqrt{0.811^2 + 0.263^2} = 0.853 \text{ ft.}$$

3. Using only vertical checkpoints to assess 3D accuracy of lidar data

This is the most common industry practice today, as checkpoints for lidar data are usually surveyed to assess vertical accuracy. 3D accuracy can be assessed even without checkpoints suitable for assessing horizontal accuracy. The new standards in section 7.6 provide the following equation to reliably estimate the horizontal accuracy of lidar datasets:

The horizontal accuracy of lidar data estimated from the above equation is a function of the following main contributors to the error budget in lidar:

- Flying altitude above mean terrain (in meters)
- GNSS positional errors derived from published manufacturer specifications or processing reports (in meters)
- IMU errors derived from published manufacturer specifications (in degrees)
- To illustrate the use of this equation, assume a lidar project was flown with the following specifications:
- Flying altitude above mean terrain: 2500 m
- GNSS positional errors: 0.07 m
- IMU roll or pitch errors: 10 arc seconds
- IMU heading errors: 15 arc seconds

$$RMSE_H = \sqrt{(GNSS\ positional\ error)^2 + \left(\frac{\tan(IMU\ roll\ or\ pitch\ error) + \tan(IMU\ heading\ error)}{1.478} * flying\ height\right)^2}$$

Figure 3: Imagery-based 3D model of the National Museum of the United States Air Force, Dayton, Ohio
Courtesy of Woolpertand the United States Air Force

Using the above equation, the estimated horizontal accuracy ($RMSE_H$) of the lidar point cloud that was produced from the aerial acquisition mission flown with the above parameters and instruments is 0.23 meters (or 0.75 feet). To calculate 3D accuracy, use the following equation, assuming the vertical accuracy of 0.263 meters computed in **Table 1**:

$$RMSE_{3D} = \sqrt{RMSE_H{}^2 + RMSE_V{}^2} = \sqrt{0.75^2 + 0.263^2} = 0.853 \text{ ft.}$$

Since the horizontal accuracy ($RMSE_H$) is estimated based on the sensor model, we did not incorporate the survey errors in deriving it, as they did not play a role.

Final remarks

As the industry adopts the latest version of *ASPRS Positional Accuracy Standards for Digital Geospatial Data,* more emphasis will be placed on the new 3D accuracy term. This is true for federal programs such as the USGS 3DEP. This article helps users calculate 3D accuracy for their projects under different circumstances of checkpoint availability.

Download the ASPRS standards document using the following link tinyurl.com/dhp3tert or QR code:

Purchase a printed book of the standards using the following link: tinyurl.com/4radm237.

Acknowledgments

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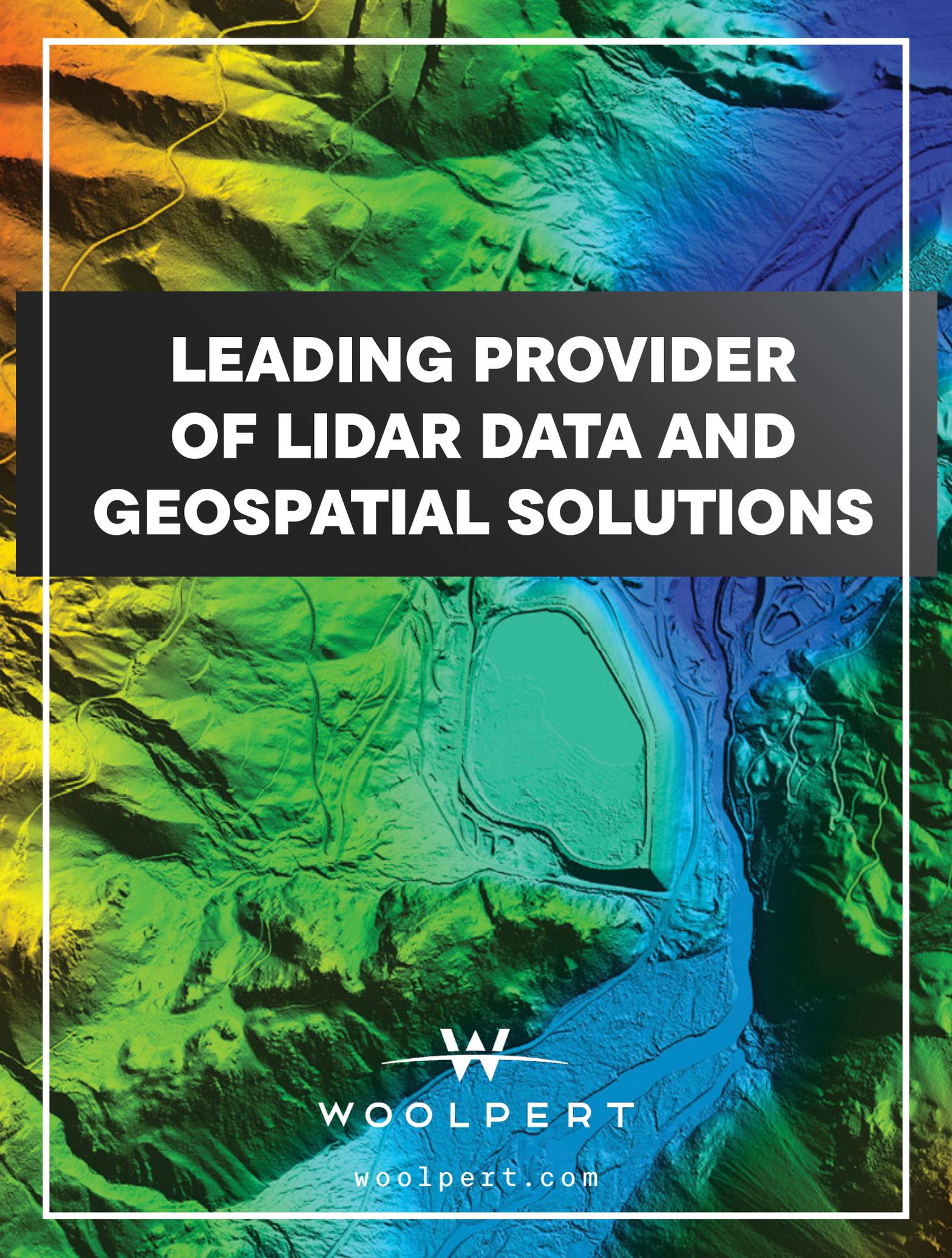
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A Tutorial for 2025

Part IV: UAV-Lidar

In recent years, both the miniaturization of sensors and advances in remote-controlled aerial platform technology have enabled the integration of scanning lidar (light detection and ranging) instruments into unmanned aerial vehicles (UAVs), also known as UAS (uncrewed aerial systems), RPAS (remotely piloted aerial systems), or colloquially referred to as drones. UAV laser scanning (ULS) delivers very dense 3D point clouds of the Earth's surface and objects thereon like buildings, infrastructure, and vegetation. In contrast to conventional airborne laser scanning (ALS), where the sensor is typically mounted on a crewed aircraft, ULS utilizes UAVs as measurement platforms, which allow lower flying altitudes and velocities, resulting in higher point densities and, thus, a more detailed description of the captured surfaces and features.

Part I of this tutorial explained the fundamentals of laser ranging, scanning, signal detection, and the geometric and radiometric sensor models. While ALS and ULS are similar in the fundamental aspects of operation, the benefit of ALS is large-area acquisition of topographic data. In contrast, ULS can be thought of as close-range ALS. This facilitates applications which require high spatial resolution.

ULS is a dynamic, kinematic method of data acquisition. The laser beams are continuously sweeping in the lateral direction. Together with the forward motion of the platform, this causes a swath of the terrain and objects below the UAV to be captured. Distances between sensor and targets are determined by measuring the time difference between the outgoing laser pulse and the portion of the signal scattered back from the illuminated targets into the receiver's field of view (FoV). Like laser
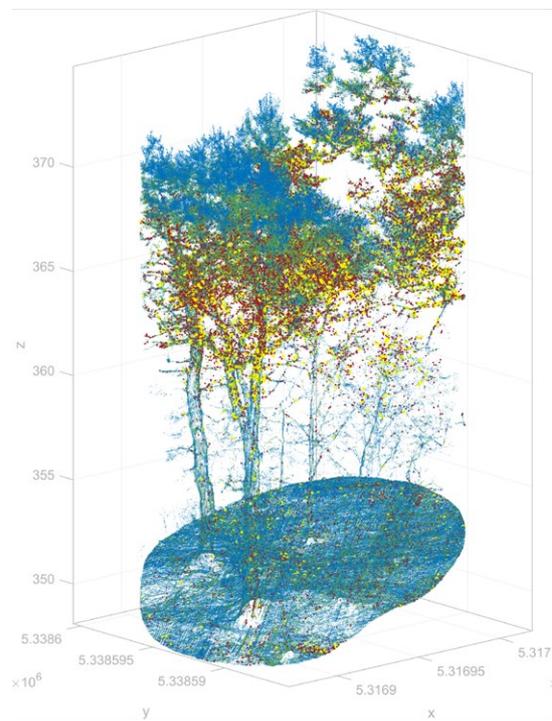
scanning in general, ULS is therefore a sequentially measuring, active remote sensing technique.

In order to obtain 3D coordinates of an object in a georeferenced coordinate system (e.g., WGS84, ETRS89), the position and orientation of the platform as well as the scan angle must be continuously measured in addition to the distances. Thus, both ULS and ALS are kinematic, multi-sensor systems in which each laser beam has its own absolute orientation. The use of a navigation device consisting of a GNSS (Global Navigation Satellite System) receiver and an IMU (inertial measurement unit) is just as indispensable for ULS as it is for ALS.

(a) Echo number

Legend: 1st ■ 2nd ■ 3rd ■ 4th ■ echo

BY GOTTFRIED **MANDLBURGER**

(b) Reflectance　　　　(c) Deviation
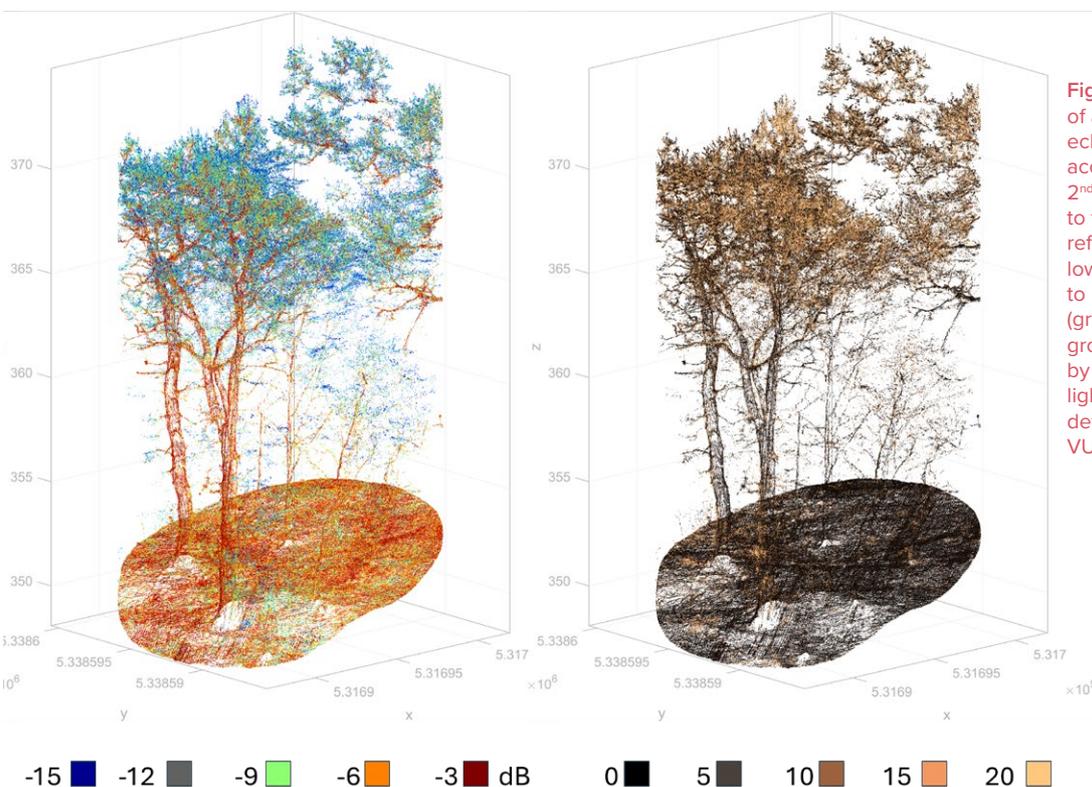
Figure 1: 3D UAV-lidar point cloud of a forest plot: (a) colored by echo number - 1st echoes (blue) accumulate in the canopy whereas 2nd, 3rd, and 4th echoes penetrate to the ground; (b) colored by reflectance - small twigs feature lower reflectance (blue) compared to laser returns from branches (green), and from stems and bare ground (orange, red); (c) colored by pulse shape deviation - dark/light color tones refer to high/low detection accuracy. Sensor: RIEGL VUX-100[25].

ULS is a polar measurement system, i.e., a single measurement is sufficient to obtain the 3D coordinates of an object. This is particularly advantageous for dynamic objects such as treetops or high-voltage power lines, which are constantly moving owing to wind.

The ideal laser beam is infinitely small, but actual laser beams can be considered more like cones of light with a narrow opening angle (beam divergence). For ULS, typical diameters of the illuminated spot on the ground (footprint) range from cm to dm, depending on the flight altitude and beam divergence of the sensor. Due to the limited footprint, multiple objects along the laser line-of-sight can potentially be illuminated by a single

pulse. In such a situation, sensors operating with the time-of-flight measurement principle can return multiple points for a single laser pulse. This so-called multi-target capability, combined with high measurement rates, results in unprecedented 3D point densities for the detection of semi-transparent objects such as forest vegetation (**Figure 1**) and power-line infrastructure.

In addition to signal runtime, ULS sensors typically provide additional attributes for each detected echo, with virtually all sensors returning at least the signal strength, also known as intensity. In particular, sensors which record the full echo waveform often also provide calibrated reflectance and

detection quality indicators for each echo (**Figures 1b and 1c**). The strength of the backscattered signal depends on the laser wavelength used, which ranges from the visible green to the near-infrared part of the spectrum. Green laser radiation (λ=532 nm) can penetrate water and is therefore used in laser bathymetry to detect the bottom of clear and shallow waters, as discussed in Part III of this tutorial. Infrared wavelengths (λ=903/905/1064/1535/1550 nm), on the other hand, have better reflection properties for vegetation, soil, impervious surfaces, etc. Therefore, infrared lasers are the first choice for topographic mapping, forestry applications, infrastructure detection, etc.

Another similarity between ALS and ULS is data acquisition with partially overlapping flight strips. The overlap area forms the basis for (i) checking the strip matching accuracy and (ii) the geometric calibration of the sensor system through strip adjustment. ULS is particularly well suited for mapping corridors (river courses, narrow mountain valleys, forest transects, buildings in narrow street canyons, etc.). While manual control of the UAV is limited to visual line of sight (VLOS) operation, regular scan grid patterns are usually implemented via waypoints, which, with the appropriate authorization, also allow for beyond visual line of sight (BVLOS) flight.

The first commercially available UAV laser scanners appeared around 2015. At this time, ALS was already established as the prime method for capturing large-area terrain elevation data. While forestry and flood risk management were the driving forces for ALS around the turn of the century, it is nowadays predominantly the automotive industry which boosts sensor development. Indeed, since driver assistance systems make use of lidar sensors, this has promoted the development of low-cost sensors for the mass market. Many of these sensors are now integrated on to UAVs and used for 3D mapping. As a consequence, a broad range of UAV lidar sensors is available spanning from low-cost consumer-grade to high-end survey-grade instruments.

In the next sections, the different sensor concepts are introduced, followed by a discussion of the individual components, with respect to platform navigation as well as ranging and scanning. The tutorial concludes with a discussion of selected state-of-the-art sensors, examples of applications, and a list of related readings.

Sensor concepts

UAV lidar sensors can be divided into the following categories (**Figure 2**):

1. Single-beam scanning lidar
2. Rotating multi-beam profile array lidar
3. Multi-beam scanning lidar
4. Solid-state lidar

The basis of the first category is the conventional concept of linear-mode lidar systems, but with significantly reduced size and weight. With typical sizes of around 30x20 x20 cm and a weight of approximately 4 kg, these systems represent miniaturized versions of mature ALS sensors with a much smaller form factor and weight. Typically, a single high-class solid-state laser unit with a pulse repetition rate (PRR) in the
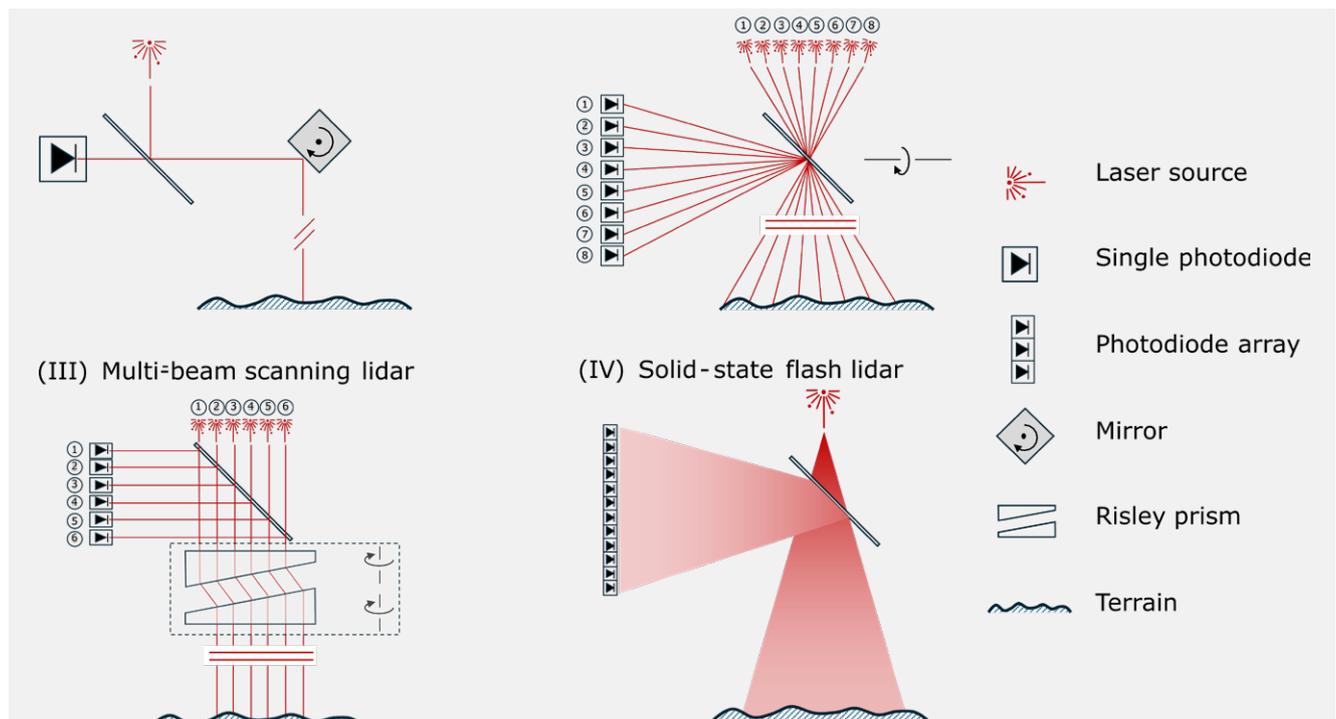
Figure 2: Schematic diagram of the various UAV lidar sensor concepts.
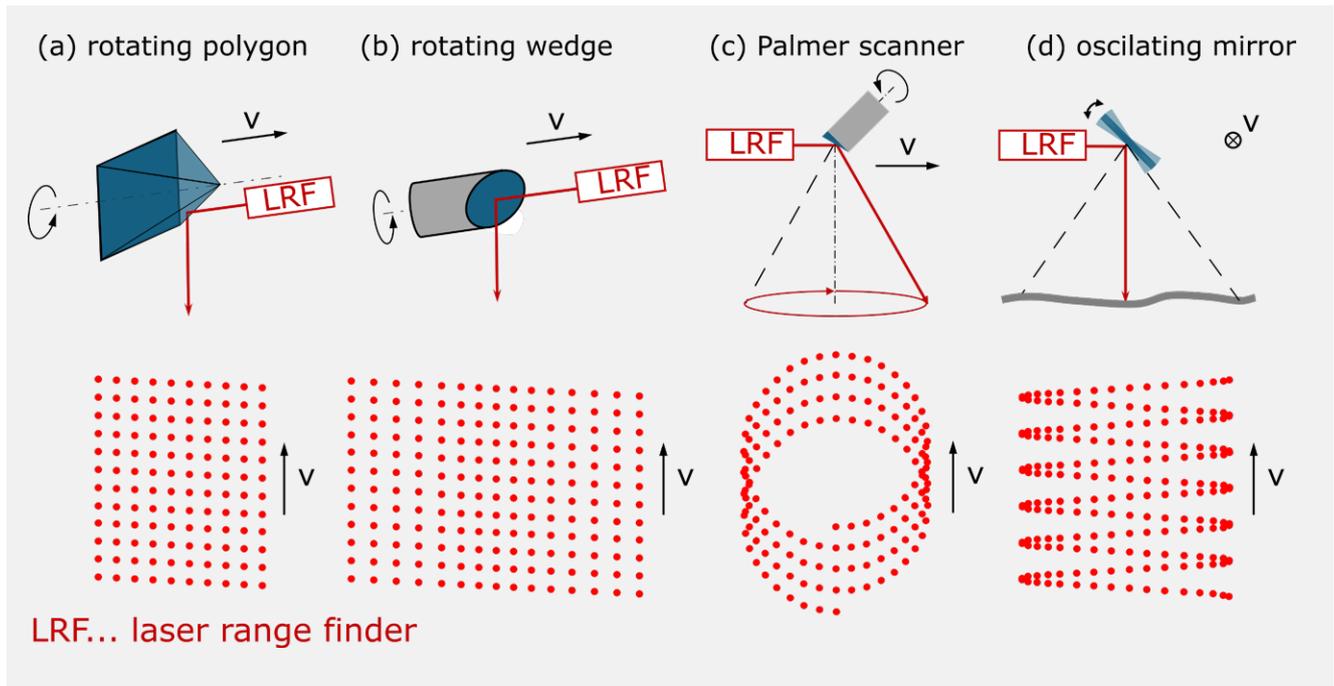
Figure 3: Strategies for laser beam deflection used in single-beam scanning UAV-lidar.

MHz-domain is coupled with a rotating or oscillating beam deflection unit and a high-quality detector, typically consisting of an avalanche photon diode (APD) and a downstream AD converter, optionally with full-waveform digitization capabilities. These systems feature long measurement distances (~500 m) and provide high ranging precision (5-10 mm) as well as small and circular laser footprints with typical diameters of 5-8 cm when flown at 100 m above ground level (agl). To ensure eye safety, instruments in this class predominantly use near-infrared lasers with a wavelength of 1550 or 1064 nm.

Rotating multi-beam scanners do not have a beam deflection unit but use an array of diode lasers instead. All lasers fire at the same time with a single-beam PRR of 10-50 kHz. The laser beams form a fan with a typical FoV of 30°. The return signal of each laser is directed to an individual (silicon) APD receiver. The entire transceiver bundle rotates around a common axis, thus providing a 360° view. As multiple transceivers are employed, the quality of a single transceiver is lower compared to the transceiver unit of the conventional single-beam scanning lidar sensors. This applies to both the maximum measurement range and the laser beam divergence. Nevertheless, such sensor concepts are a core technology in the automotive industry for creating detailed 3D maps of a vehicle's surroundings. This enables effective driver-assistance and even autonomous driving by precisely detecting and tracking objects. A major advantage compared to conventional survey-grade sensors is the much lower price. The alignment of multiple transceivers is a non-trivial task,

however, especially for systems featuring more than 100 channels.

To mitigate the multi-channel alignment problem, a hybrid multi-beam scanning lidar concept was successfully established, which uses a few transceivers and a compact beam-steering device. Typically, six pulsed laser diodes and corresponding APD detectors are used as transceivers and beam deflection is implemented with a Risley prism, which consists of two (glass) wedge prisms that are arranged coaxially and rotate independently of each other around the optical axis. Depending on the current orientation of the wedge prisms, the laser beams are deflected differently due to refraction at the interfaces between glass and air. Depending on speed and direction of rotation, Risley prisms allow the creation of arbitrary scan patterns, ranging from straight lines via circles to spirals and floral patterns. The latter are used in the automotive industry to
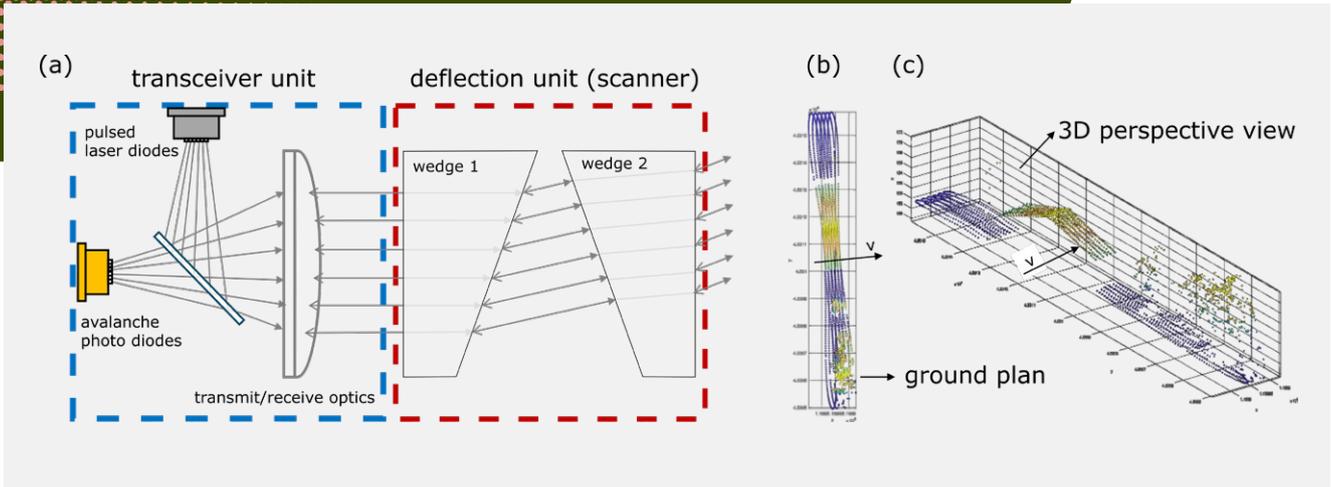
Figure 4: (a) lidar and scanning unit of the Livox Avia multi-beam scanning lidar; (b) and (c) ground plan and perspective view of the object points during a full rotation of the scanning unit (six parallel figure-of-eight loops).

compile range images (3D scanning), again for driver assistance, collision avoidance, and fully autonomous driving. The former patterns (straight lines, shapes of a flat eight) are more suitable when such systems are mounted on UAV platforms, where 2D scanning is sufficient as the forward motion of the UAV provides the third dimension.

The last category is referred to as solid-state lidar, i.e. a concept without any rotating parts. The term "solid-state lidar" is used both for systems that use micro-electro-mechanical systems (MEMS) for beam deflection, and for so-called focal plane array systems, also referred to as flash lidar, which are comparable to digital cameras, where each pixel is a single APD and thus a single laser-ranging unit. APD arrays are common in Geiger-mode lidar, typically flown from very high altitude, but APD arrays can also be operated in linear mode and deployed on UAVs. Only focal plane array systems truly deserve the name solid-state, as there are indeed no

moving parts. Regardless of brand of solid-state, however, the integration on UAVs is not widespread up to now.

From the above, it can be seen that there are significant differences between individual sensor components, ranging from low-cost consumer devices to high-quality surveying equipment. The following sections, therefore, discuss the core components of a UAV lidar sensor system, i.e., GNSS, IMU, laser range finder, and scanner, in more detail.

Platform positioning – GNSS

As discussed in Part I of the tutorial, 3D lidar points are obtained by direct geore-ferencing (cf. Part I, Equation 2), which combines platform position and attitude with laser scanner measurements. The positioning of the UAV is based mainly on global navigation satellite systems (GNSS), with data from various systems such as GPS, Galileo, GLONASS and Beido being used jointly today.

For UAV applications, GNSS is used twofold: (i) a base station with known

coordinates in a well-defined reference system (e.g., WGS84 or ETRS89) serves as the basis for surveys with precisio in the cm range, and (ii) the UAV itself uses GNSS first to navigate to waypoints and fly predefined routes using real-time kinematic (RTK) corrections, either broadcast by the base station or by a GNSS network provider, and second to record the raw GNSS signals for calculat-ing a single best estimate trajectory (SBET) in post-processing.

The GNSS device consists of an antenna and a receiver. For base sta-tions, high-level choke-ring or radome antennae are used, which provide good multi-path suppression – this is important for ground-based installa-tion. On the UAV, lighter and cheaper antenna types are used. Patch antennae are small and cheap and are therefore favored whenever accuracy demands are moderate. In most cases, helix antennae are used for UAVs. They have a typical cylindrical shape, and the actual antenna is a spirally wound wire. Helix

antennae provide omnidirectional signal reception, which makes them susceptible to multi-path effects. This is not critical, however, as the platform is in the air. On the receiver side, either (i) single-, (ii) double-, or (iii) multi-frequency devices are available. This refers to the ability of the receiver to simultaneously receive the individual GNSS frequencies (L1, L2, L5). Obviously, multi-frequency receivers outperform single- and double-frequency devices, which in turn are cheaper. An important parameter is the measurement frequency. Today frequencies from 1 to 10 Hz are common. Manufacturers of GNSS devices for UAVs include uBlox and Septentrio (part of Hexagon), for example. Depending on the quality of the components, absolute coordinate uncertainties of the post-processed trajectory positions range from around 3 to 10 cm.

Platform orientation – IMU

Next to the position, the platform's attitude must be precisely known at all times. IMUs continuously measure the platform's motion using (i) gyroscopes, (ii) accelerometers, and (iii) optionally a magnetometer. Gyroscopes measure angular velocity (i.e. rotation rate) around three axes. Integration of angular velocity over time yields the actual orientation angles, e.g. roll, pitch and heading. Accelerometers, in turn, measure linear acceleration (i.e. velocity change), again along the three axes. Double integration of the accelerometer measurements yields positions with respect to the navigation frame (e.g., north/east/down): thus the IMU-accelerometer supports GNSS-based positioning. The optional magnetometer is used for correcting the heading angle with the Earth's magnetic field. In general, IMUs feature a measurement frequency of 100-1000 Hz. The higher the IMU frequency, the better can high-frequency vibrations of the platform be captured.

In general, two different IMU concepts are in use: (i) fiber-optic systems and (ii) MEMS-based IMUs. Fiber-optic IMUs are more precise, but also more expensive and heavier. Therefore, MEMS-based IMUs are predominantly used for UAV-lidar, as they are compact, lightweight and cheap. Furthermore, the accuracy can be increased by rigorous calibration and by using multiple MEMS-IMUs in parallel. The accelerometers use tiny test masses suspended on springs, whose deflection is measured by capacitive sensors. The gyroscopes use vibrating structures (tuning forks) which experience a Coriolis force once the sensor/platform rotates. This results in a measurable displacement that is proportional to the angular velocity. Fiber-optic gyros, in turn, use light interference in the fiber bundle for measuring rotation rates.

No matter which technology is used, the final six degrees-of-freedom (6-DoF) trajectory consists of positions (x, y, z) and orientations (roll, pitch, heading) parametrized over time (t) and is achieved by fusing both GNSS- and IMU-measurements in post-processing, typically using Kalman filtering. The integration of GNSS observations is necessary, as IMUs provide only relative measurements, and the errors accumulate when integrating over time (drift). Achievable accuracies are in the range of 0.015° for the roll and pitch angles, 0.035° for the heading angle, and 2-5 cm for the position. In general, fiber-optic IMUs outperform MEMS-based IMUs with respect to accuracy. On the other hand, MEMS-based IMUs often provide higher measurement rates and are therefore better suited to capture high-frequency platform movements.

Ranging

In Part I of this tutorial, we discussed the general principle of laser ranging in detail and concluded that distinct laser echoes are either detected directly within the receiver electronics based on trigger thresholds (discrete echo systems) or by digitizing the entire backscattered echo pulse and detecting individual echoes within the sampled full echo waveform. The latter can be done either online in the instrument or in post-processing, if the waveform is additionally stored on disk. Both technologies are also available for UAV-lidar. Survey-grade single-transceiver instruments often operate based on full-waveform digitization, while multi-beam sensors tend to use discrete echo detection.

A major difference between survey- and consumer-grade sensors is the laser technology used. Typically, ranging can be conducted using relatively cheap diode lasers and more expensive solid-state lasers or fiber lasers. Diode lasers, frequently used in the automotive industry, emit laser radiation at a wavelength of 905 nm (near-infrared). The advantage of using this wavelength is that standard silicon detectors can be used, which makes the lidar sensors cost-effective. With respect to eye-safety, the use of a longer wavelength, e.g. the 1550 nm produced by the erbium-doped fiber laser, is beneficial as more laser power can be used without compromising eye safety. This is especially relevant for UAV-lidar as the sensors are operated close to

Table 1: Specifications of selected UAV-lidar sensors.

Sensor	Manufacturer	Category	Mass	Dimensions (L x W x H)	Wavelength	Maximum Range	Precision/ Accuracy
			[kg]	[mm]	[nm]	[m]	[mm]
VUX1-UAV22	RIEGL	I	375.00	227 x 209 x 129	1550	750-1601)	5/10
miniVUX-3UAV	RIEGL	I	1.75	243 x 111 x 85	905	170	10/15
VUX-12023	RIEGL	I	2.30	242 x 117 x 126	1550	760-2001)	5/10
Puck LITE	Velodyne/Ouster	II	0.59	103 x 103 x 72	903	100	--/30
Alpha Prime	Velodyne/Ouster	II	3.50	166 x 166 x 141	905	300	--/30
CL-360HD2	Teledyne Optech	I	3.50	310 x 160 x 116	1550	730-451)	4/5
CL-90	Teledyne Optech	I	4.10	300 x 213 x 209	1550	633-1761)	5/10
EchoONE	Teledyne Optech	I	1.65	170 x 144 x 120	1535	270-2201)	5/10
Avia	Livox	III	0.50	91 x 61 x 65	905	250	20/50
Zenmuse L2	DJI	III	0.90	155 x 128 x 176	905	250	20/50
Zenmuse L3	DJI	I	1.60	192 x 162 x 202	1535	2000-7001)	5/10
H600	GreenValley	I	1.30	179 x 114 x 127	1535	~300	5/50
TrueView 540	GeoCue	I	1.55	210 x 112 x 131	1535	400	5/15
Navigator	YellowScan	I	4.20	350 x 160 x 190	532	1202)	30/30
VQ-840-GL	RIEGL	I	10.5	360 x 280 x 200	532	3002)	15/20
VUX-820-G	RIEGL	I	5.70	368 x 172 x 180	532	3002)	15/20

1) ranging performance is dependent on pulse repetition rate
2) for bathymetic scanners, the maximum range is limited by operational constraints concerning water penetration rather than by the lidar's ranging performance

the ground with typical flying altitudes of around 100 m agl. Nevertheless, the use of a 1550-nm laser implies the use of expensive InGaAs photodiodes. For this reason, fiber lasers are used only in survey-grade UAV-lidar sensors, which offer higher peak power, better beam quality, smaller beam divergence, higher PRR, and potentially lower pulse duration, in exchange for the higher cost. Diode lasers, in turn, are not only cheaper but also more compact, which is relevant as payload is of great concern for UAV-lidar.

Scanning

As with conventional ALS, UAV-lidar also captures the Earth's surface based on flight strips. For single- or multi-beam scanning lidar systems, areal coverage with 3D points requires (i) the forward motion of the UAV platform and (ii) a beam deflection unit systematically steering the laser rays below or around the sensor. **Figure 3** shows some of the typical beam deflection mechanisms used in ULS.

If scanning is performed in a vertical plane, rotating polygonal mirrors operated with a constant speed produce

Pulse Rate	Beam Divergence	Footprint @ 50 m agl	FOV	Channels
[kHz]	[mrad]	[mm]	°	
50-1200¹⁾	0.35	17.5	360	1
100-300	1,6 x 0,5	80 x 25	360	1
150-2400¹⁾	0.4	20	100	1
300	3,0 x 1,2	150 x 60	360 x 30	16
2300	2,1 x 1,1	105 x 55	360 x 40	128
200-2000¹⁾	0.3	15	360	1
50-500¹⁾	0.3	15	90	1
400-600¹⁾	0.5	25	90	1
240	0,5 x 5,0	25 x 250	70	6
240	0,4 x 1,2	30 x 90	70	6
100-2000¹⁾	0.25	24	80 x 80	1
100-550	--	--	80	1
500	--	--	75	1
20	4	200	40	1
50-200	1-6	50-300	40	1
50-100	1-6	50-300	40	1

Figure 5: Integration example: RIEGL miniVUX-3UAV (left) and DJI Zenmuse L2 (right), each mounted on a DJI Matrice 350 RTK multicopter UAV.

a linear point pattern on the ground with equal point spacing in the nadir direction and slightly increased spacing at the strip boundary. Depending on the number of mirror facets (2-4), a FoV of 60-160° is achievable. Interesting variants are available on the market, where the individual mirror facets are slightly tilted, enabling forward, nadir and backward looks in a single revolution of the mirror wheel, which is especially beneficial for scanning vertical structures and (semi-transparent) vegetation. Rotating mirrors also allow panoramic scanning (FoV=360°) using a single mirror facet tilted by 45°. Oscillating mirrors constantly swing between two positions and produce a zigzag pattern on the ground, with the slight disadvantage of a less homogenous point distribution, especially at the strip border, due to the deceleration and re-acceleration of the mirror. Conical (Palmer) scanning is also used in UAV-lidar, notably for UAV-based laser bathymetry (cf. Part III of this tutorial).

Risley prisms use ray refraction at the air-glass-air interfaces for beam steering, as opposed to reflection at a mirror surface. Risley prisms are used in the family of hybrid multi-beam scanning lidar sensors. As stated before, the two beveled glass wedges of the Risley prism can be operated independently and produce arbitrary scan patterns. In the UAV context, however, the predominant scan pattern resembles a flat figure-of-eight loop. This causes the laser beam's line of sight to be directed slightly forward and backward at the edge of the strip and almost towards the nadir in the center of the strip. The disadvantage of refraction-based beam steering is that scattering in the glass slightly deteriorates the beam quality. **Figure 4** shows the sensor and scanning concept of the

Figure 6: 3D RGB-colored UAV-lidar point cloud of an agricultural warehouse captured with (a) RIEGL miniVUX-3UAV and (b) DJI Zenmuse L2.

Livox Avia instrument, a representative multi-beam scanning lidar instrument.

Finally, no distinct beam deflection unit is necessary for multi-beam profile-array scanners and solid-state flash lidar systems. For the former, the entire transceiver bundle rotates 360° around a common axis, which for UAV-integrations is either horizontal or slightly tilted. This kind of panoramic scanning is beneficial for scanning narrow street canyons or narrow valleys as it allows capturing 3D points both below and above the platform.

Examples of sensors and integration

Table 1 lists the specifications of selected commercially available UAV lidar sensors, extracted from the data sheets published by the individual manufacturers.

The table lists a series of survey-grade single-beam scanning lidar sensors (category I) from various manufacturers with a measurement precision

below 1 cm (VUX1-UAV, VUX-120, CL-360HD2, CL-90, Zenmuse L3, H600, TrueView540). All these sensors use a high-class 1535- or 1550-nm laser and a corresponding high-quality receiver. from 160 to 2000 m, depending on instrument and pulse repetition rate. For these instruments, the latter is in the range of 100 kHz to 2.4 MHz. Devices with high PRR, in excess of 2 MHz, also offer measurement modes with reduced pulse frequency, whereby the maximum measurement distance is extended due to the higher laser power available for a single laser pulse. The survey-grade instruments also provide the smallest beam divergences (0.3-0.5 mrad), yielding a small laser footprint on the ground of 15-25 mm.

The rotating multi-beam profile array sensors (PuckLITE, Alpha Prime; category II) and the multibeam scanning lidar sensors (Avia, Zenmuse L2; category III), in turn, are typically lighter than their category I counterparts. The Zenmuse L2, for example, weighs less

than 1 kg, including IMU and a 20 MP RGB camera. These systems all use 905-nm diode lasers. They typically exhibit low beam divergence in one direction and higher divergence in the orthogonal direction, which leads to elliptical footprint areas on the ground. The achievable spatial resolution is limited by the larger of the two diameters as well as by the point-to-point distances. The latter depends on the PRR, the rotation speed of the scanning unit or the laser bundle, and the flying altitude. A typical feature of multi-beam sensors is that the pulse rate of a single laser source is moderate (2-40 kHz), but the resulting net pulse rate can be high due to coupling multiple channels. The AlphaPrime, for example, has a pulse frequency of 2.4 MHz, which results from 128 channels, each with a PRR of approximately 20 kHz.

Table 1 also lists three topobathymetric UAV laser scanners (Navigator, VQ-840-GL, VUX-820-G), which use a green laser at 532 nm. All three are category I instruments (single-beam
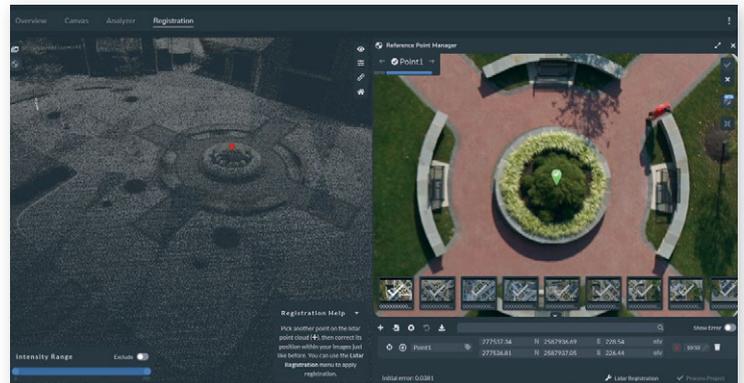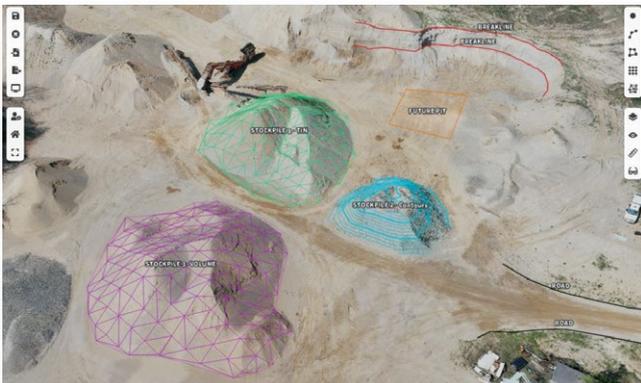
Figure 7: (a) True-color 3D point cloud of a double-track high-voltage power line captured with the DJI Zenmuse L3 laser scanner. The white rectangle marks the detail shown in: (b) Zenmuse L3 (September 2025) and (c) Zenmuse L2 (August 2024).

the VQ-840-GL with a beam divergence of 1 mrad requires a certain minimum flight altitude (>120 m agl).

All the listed sensors are typically mounted on multicopter UAV platforms and operated in VLOS mode, i.e. with permanent sight contact between pilot and UAV. Depending on the total payload, today's multicopters allow flight times of around 20-45 minutes with one battery set. When the integration is on fueled aircraft and operated in BVLOS mode, much longer flight endurance is possible, opening the way for large-area 3D mapping in high resolution. This applies to all possible aerial systems including multicopters, helicopters, fixed-wing UAV, and systems supporting vertical takeoff and landing (VTOL). **Figure 5** shows an example of integrations of two different UAV-lidar sensors on the same multicopter platform.

Application examples
The main advantages of UAV-lidar over conventional ALS from crewed aircraft are (i) the higher spatial resolution and (ii) the lower mobilization costs. These come at the expense of limited area coverage due to limited endurance, lower flight altitude entailing smaller swath widths, and lower flight speed. Thus the use of UAV-lidar is always economical when the size of the area of interest is moderate and when repeat data acquisitions are required to capture processes.

The fields of application include:
- 3D mapping of topography and shallow-water bathymetry
- 3D mapping of urban scenes including as-built 3D documentation of construction sites (houses, bridges, dams, etc.)
- 3D vegetation mapping (forest extent, forest structure,

scanning lidar) and feature full-waveform digitization, which is obligatory for bathymetric scanners. For eye-safety reasons, these systems have a relatively large beam divergence of 4 mrad (Navigator) or 1–6 mrad (VQ-840-GL). In all cases, the devices must be operated in such a way that the nominal ocular hazard distance (NOHD) is maintained. This means, for example, that operating

Figure 8: (a) True-color 3D point cloud of the Pielach River captured in July 2025 with the YellowScan Navigator topobathymetric laser scanner; (b) cross-section with points colored according to classification.

biomass estimation, tree species classification, diameter at breast height derivation, urban vegetation, etc.)

- 3D mapping for monitoring of natural or artificial processes including landslides, rockfalls, avalanches, glacier retreat, hydromorphological changes, open pit mining, etc.
- 3D corridor mapping including powerlines, railways, motorways, creeks in steep alpine terrain, etc.
- Archaeology, especially detection and documentation of remains hidden under vegetation canopy or submerged in lakes or the sea
- Ecology, especially detection of standing and lying dead wood, high-resolution wetland mapping, identification of ecological niches, etc.
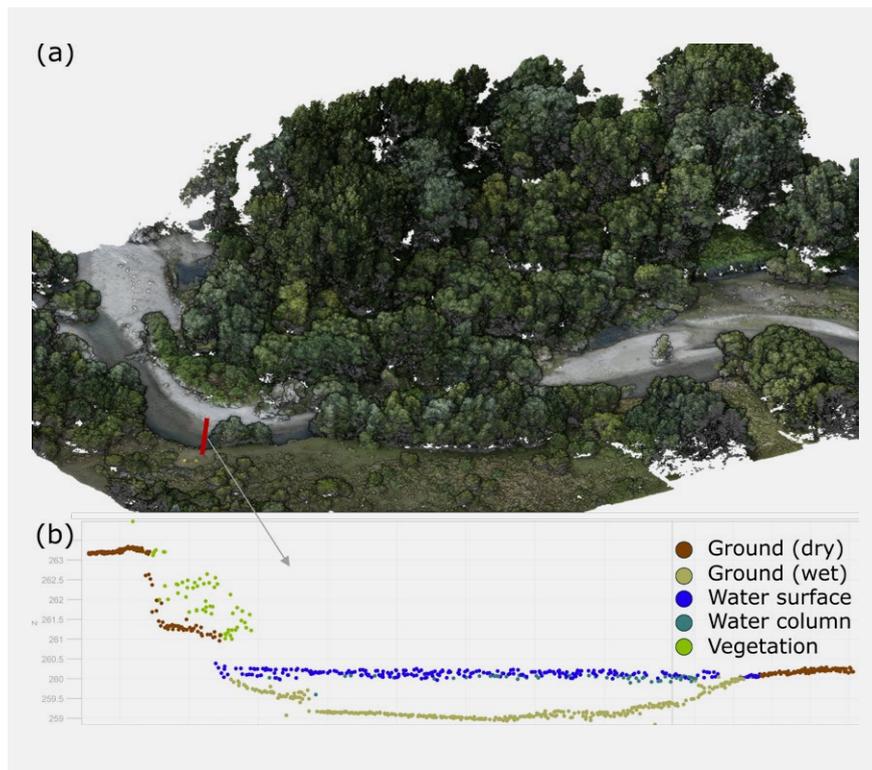- Agriculture, especially in the context of precision farming, to monitor plant growth and phenology

Figures 6-9 are results of UAV-lidar applications. **Figure 6** shows an agricultural warehouse captured with two different sensors, a single-beam 360°-scanning lidar and a multi-beam scanning lidar with 75° FoV. Both sensors capture the warehouse and its surroundings and also provide RGB-colored point clouds based on the integrated cameras. The 360° scanner provides better coverage of the vertical walls. This could be compensated, however, by tilting the multi-beam

scanner sideways, which is supported by the instrument.

Figure 7 shows the 3D point cloud of a double-track high-voltage power line and provides an example of corridor mapping. The scene shows points on the individual cables and power poles, but also details such as insulators, which can normally only be captured with terrestrial laser scanning, but are well resolved with a compact short-range UAV-lidar.

Figure 8 showcases topobathymetric UAV-lidar. The scene, from the pre-Alpine Pielach River in Lower Austria and the surrounding alluvial forest (nature conservation area Neubacher Au), was captured with an integrated sensor consisting of a topobathymetric lidar unit and an RGB camera. The detail in **Figure 8** shows a representative section of the point cloud classified into dry and submerged ground, water surface, water column, and vegetation resulting from data post-processing in the manufacturer's software.

Finally, **Figure 9** shows DTMs of same area captured twice in 2021 and after a major flood in 2024 with a different topobathymetric UAV-lidar system. Both datasets were rigorously georeferenced using a permanent local GNSS base station so that the DEM-of-differences shows the enormous impact of the September 2024 flood event, with total erosion (yellow to red) and deposition (green to blue) of 3600 m^3 and 5100 m^3, respectively. Data post-processing was carried out with the manufacturer's software and with the scientific laser-scanning software OPALS developed at TU Wien.

Concluding remarks

This concludes the four-part tutorial on airborne lidar for 2025. Part I discussed
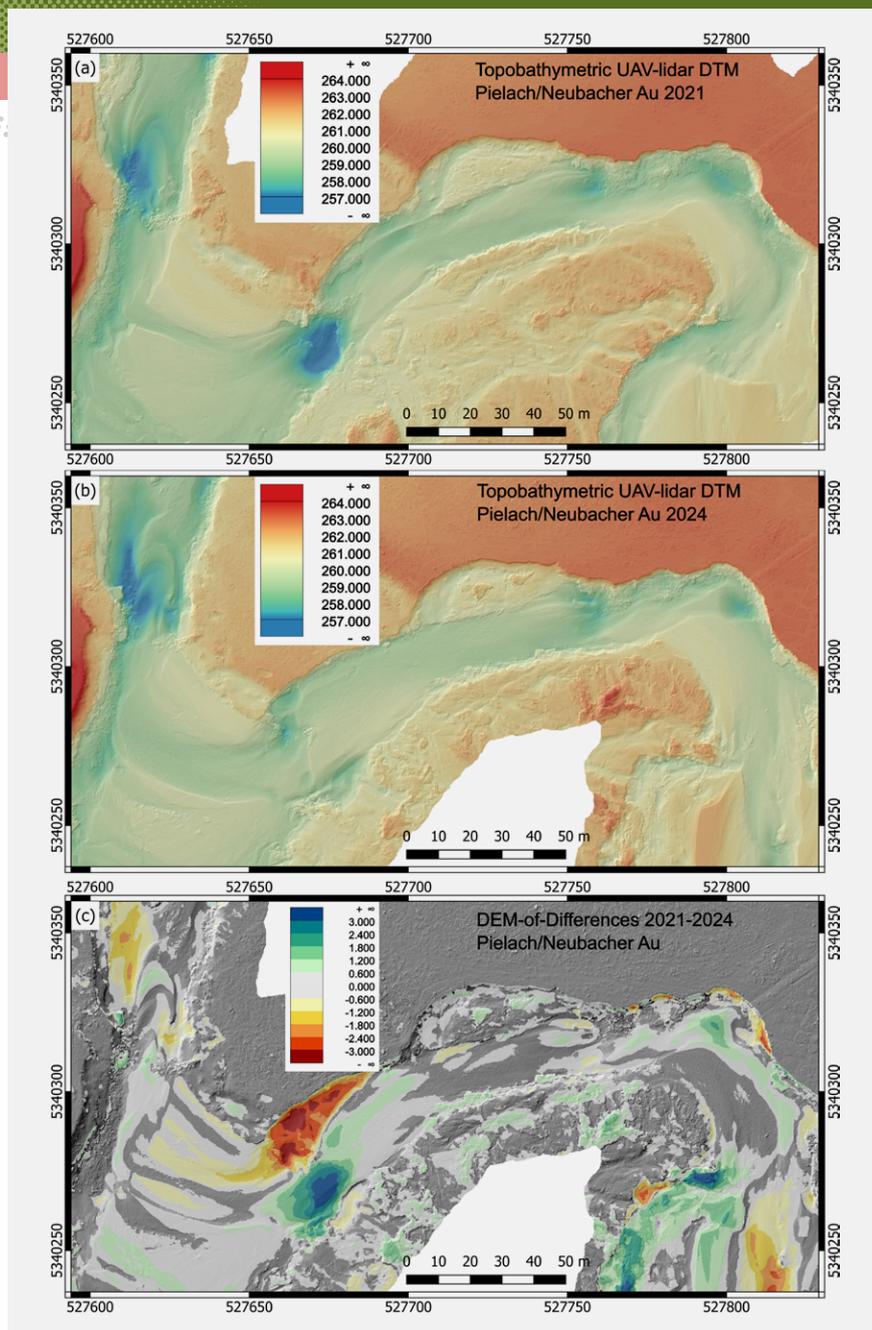
Figure 9: Color-coded and shaded DTMs of a section of the Pielach River captured twice, (a) in 2021 and (b) after a major flood in 2024, with the RIEGL VQ-840-G topobathymetric laser scanner; (c) color-coded DEM-of-differences map showing clear erosion and deposition patterns.

the basics of airborne lidar and introduced the fundamental formulae (ranging, laser-radar equation, direct georeferencing). Part II focused on integrated systems consisting of active lidar and passive camera sensors as well as on multispectral lidar. The general topic of Part III was laser bathymetry using water-penetrating green lasers. And, finally, Part IV provided details on UAV-lidar, which is a rapidly growing field.

I would like to thank all readers for their attention, comments, and feedback. I hope that some readers of *LIDAR Magazine* will find this compact tutorial useful. Please don't hesitate to contact me if you have any questions. I will be happy to discuss them with you. Finally, I would like to express my gratitude to the magazine team—especially Stewart Walker—for giving me the opportunity to write this tutorial. Thank you for your trust. ℹ

Dr. Gottfried Mandlburger studied geodesy at TU Wien, where he also received his PhD in 2006 and habilitated in photogrammetry with a thesis on "Bathymetry from active and passive photogrammetry" in 2021. In April 2024 he was appointed University Professor for Optical Bathymetry at TU Wien.

His main research areas are airborne topographic and bathymetric lidar from crewed and uncrewed platforms, multimedia photogrammetry, bathymetry from multispectral images, and scientific software development. Gottfried Mandlburger is chair of the lidar working group of Deutsche Gesellschaft für Photogrammetrie und Fernerkundung, Geoinformation e.V. (DGPF) and Austria's scientific delegate in EuroSDR. He received best paper awards from ISPRS and ASPRS for publications on bathymetry from active and passive photogrammetry.

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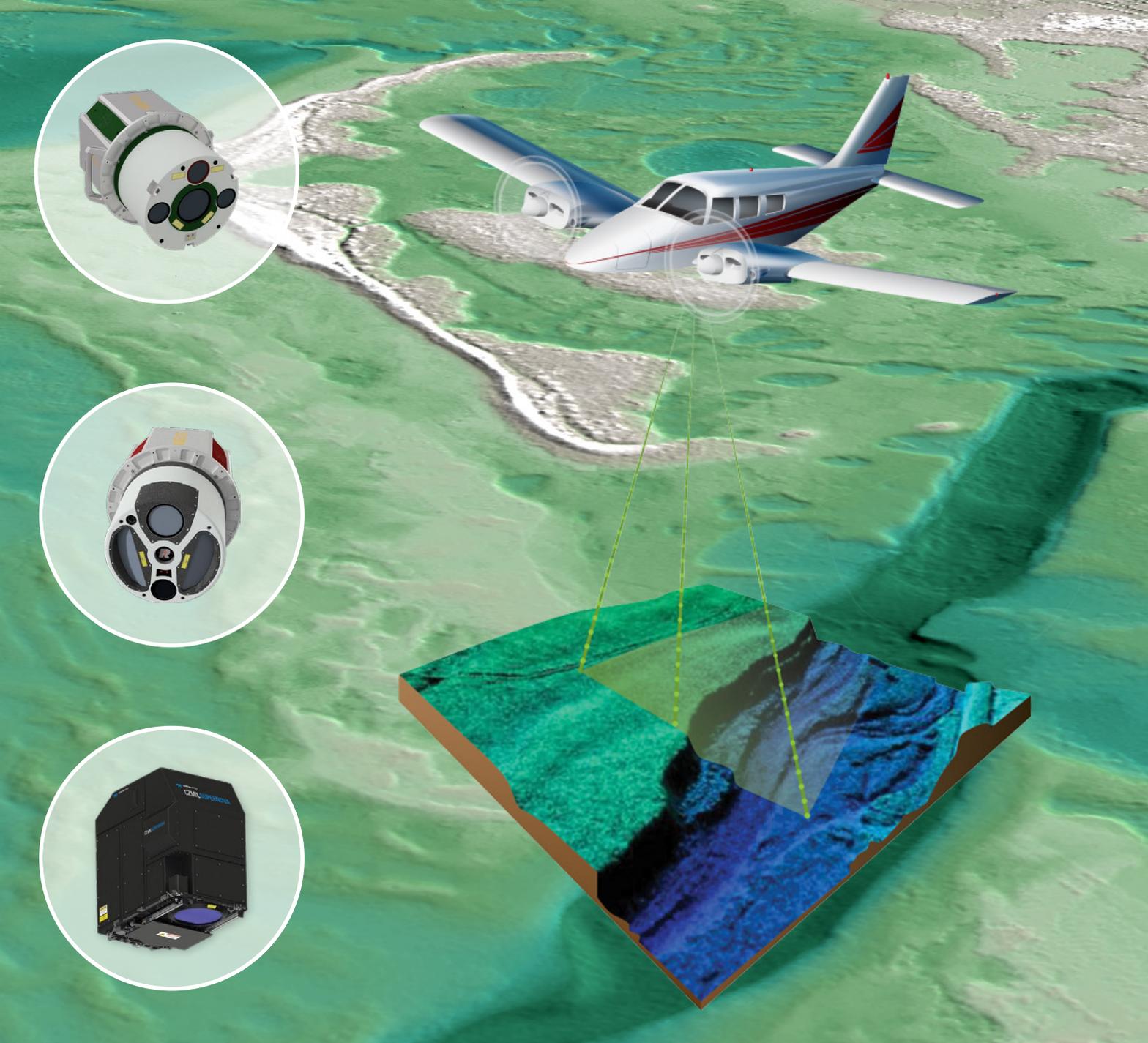
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Digitally Securing the Future: Speed and Precision for School Mapping

Fenstermaker, Lafayette 911, and Navigation Electronics used GeoCue's TrueView GO to map every school in Lafayette Parish, Louisiana, room by room, for faster, smarter emergency response.

BY BRET **BURGHDURF**

The Lafayette Parish Emergency Operations Center spearheaded and funded the mapping initiative to bring every school in the parish into the 911 CAD system. Fenstermaker led the reality-capture and mapping effort, using GeoCue's TrueView GO to scan every Lafayette Parish school for integration into the 911 CAD system. GeoCue, based in Madison, Alabama, develops and supports the TrueView GO product and associated software suite.

School safety plans have long relied on floor plans, staff knowledge, and building notes. In a crisis, however, these assets can be brittle: they go out of date, hide in filing cabinets, and quickly fall short when outside agencies, unfamiliar with the campus, arrive. Today, these tools are ready for an upgrade. By modernizing with digital mapping, districts can give first responders the clarity they need to act quickly and confidently when it matters most.

Lafayette Parish, Louisiana, decided to replace this vulnerability with a new operational reality: indoor digital maps that are standardized, searchable, and integrated directly into computer-aided dispatch (CAD) and frontline devices, so every responder sees the same picture and can be routed to a specific room as easily as to a street address.

That vision became concrete in summer 2025, when the Lafayette Parish School System (LPSS), Lafayette 911, and the consulting firm Fenstermaker became partners, enabled by Navigation Electronics, Inc. (NEI), to digitally capture every public school in the parish, room by room, and exit by exit. The technical backbone was GeoCue's TrueView GO handheld lidar and SLAM system, a lightweight, colorizing 3D mobile scanner, built for fast, accurate capture of interiors.

Over roughly six weeks, Fenstermaker scanned the district's schools at a blistering pace, often three to four campuses per day, then converted the point clouds into standardized, 2D indoor maps designed for dispatchability and situational awareness. These maps now reside where they matter most: in the CAD systems of Lafayette 911 and on the screens of patrol cars, ambulances, and fire apparatus.

"When you talk about kids and schools, they're probably our most precious commodity," said Lafayette Parish 911 director Craig Stansbury (White, 2025). "This is something we wanted to make sure we were able to provide for those first responders who are actually keeping the kids safe."

LPSS superintendent Francis Touchet Jr. was equally direct about the stakes and the district's responsibility: "Safety is our number one priority in the district. We budget appropriately to keep our kids safe. This new mapping feature with 911 is an added asset that is going to enhance response and action for the school."

The Lafayette project is more than a local success. In 2025, Louisiana enacted the "Protect Our Children and Response Act" (Act 425), which recognizes the operational importance of preparedness and rapid response and mandates advance emergency mapping for all public schools statewide. Lafayette's early adoption now serves as a model for how to implement that mandate quickly and well, with technology like the TrueView GO and workflows that scale.

Choosing the right tool for the halls

The technical lead for the project was Coy LeBlanc, MS, GISP, PWS, a remote sensing scientist at Fenstermaker and a PhD candidate focused on spatial intelligence and applied AI. LeBlanc's path to TrueView GO was methodical. He explored alternatives, tested other handheld/mobile scanners, and kept circling back to the same core requirement: fast, accurate capture of interiors that would integrate cleanly with both BIM and GIS.

The TrueView GO from GeoCue is the handheld lidar/SLAM system behind Lafayette Parish's rapid school-mapping initiative.

"We tested alternatives," LeBlanc recalled. "When Mark Forsyth from NEI brought the TrueView GO to show us, it was super easy to use, so efficient. At that point we [decided …], 'This is what we're going to use.'"

The practical advantages were hard to ignore. The TrueView GO's SLAM engine meant crews could move through long corridors, stairwells, and classrooms without GNSS and still produce a high-quality, colorized point cloud. The unit's ergonomics mattered as much as its data: technicians had to keep pace in facilities that can sprawl like small towns.

The decision became urgent when Lafayette 911, after a period of evaluation, called with a challenge that would define the project's tempo. "I told them we needed about 55 days," LeBlanc said. "They sat on it and then suddenly we had about 25. If we wanted the job, we had to move." NEI delivered the hardware and training at remarkable speed, giving Fenstermaker exactly what they needed to start scanning without delay. "Mark did a half-day of training," LeBlanc said, "and the next day we were scanning."

William Poché, owner of NEI, emphasized how training and teamwork helped set the project in motion. "Mark and our team at NEI were proud to provide the training and support that helped Fenstermaker hit the ground running with the TrueView GO," he said.

Field execution at the pace of summer

Mapping an entire parish's schools requires meticulous planning and an uncompromising timeline. Fenstermaker scheduled scanning during low-occupancy windows: summer break, holidays, and planned closures, to avoid disrupting school operations. Coordination with school resource officers and facilities teams ensured keys, access, and escorts were available as crews flowed from exterior doors to classrooms and mechanical rooms, back down corridors and into gyms.

The scanning routine became a rhythm. Technicians set and surveyed reference targets outside and along long interior axes, then re-traversed those targets during acquisition to strengthen alignment and georeferencing. Every time a technician reached a classroom, they captured ID at the source: a quick photo of the door nameplate and a record of the official room number. "We don't want to have a situation where somebody who calls in says, 'I'm in Mrs. Smith's room,' because things change and she may now be teaching on the other side of the school," LeBlanc explained. Standardizing on room numbers and common names would later pay dividends in CAD searchability. Dispatchers and officers could type "Auditorium – Lafayette High" and be routed directly to the correct space.

Fenstermaker GIS specialists use the TrueView GO handheld lidar system to map classroom interiors and common areas, part of the parish-wide effort to prepare detailed, dispatchable school maps for Lafayette 911. They collect high-accuracy interior lidar data, the key input to Lafayette Parish's comprehensive indoor mapping initiative.
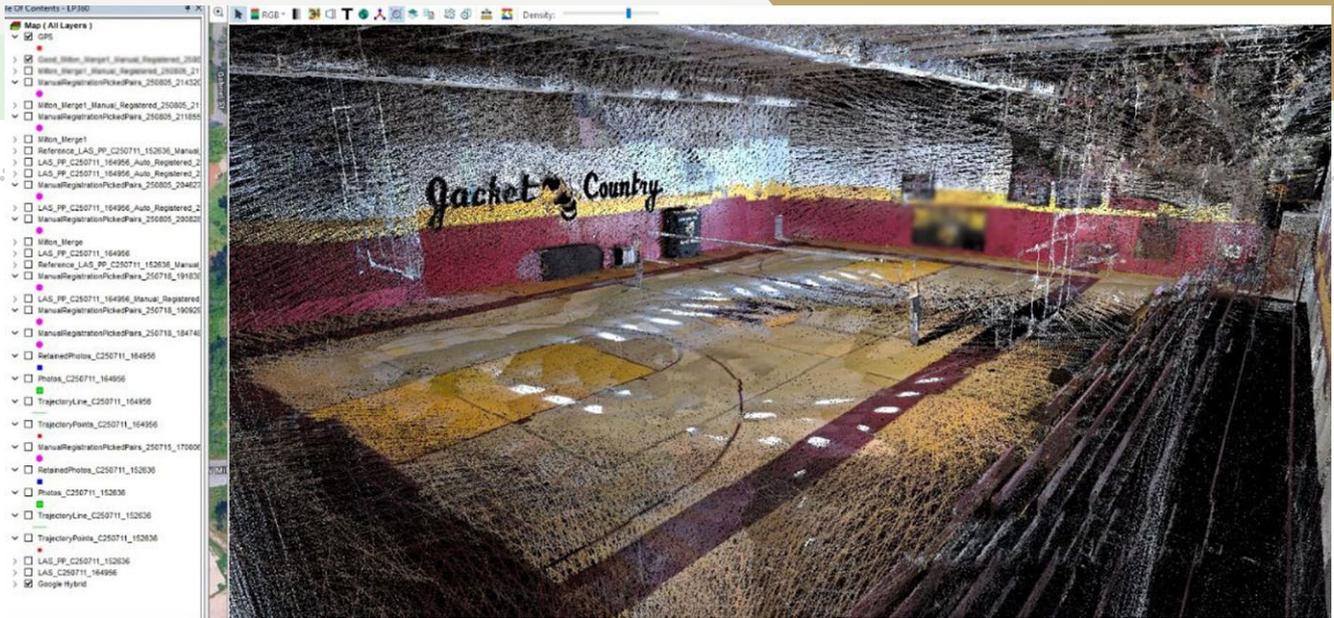
A colorized point cloud of a school gymnasium in Lafayette Parish.

A Fenstermaker GIS specialist collects a control shot to reinforce positional accuracy and strengthen the TrueView GO's SLAM alignment.

With multiple teams working in parallel, Fenstermaker typically scanned a high school in four to six hours, a middle school in about three, and an elementary school in two to three. Most crews covered three to four schools per day. "We were knocking out three to four schools a day with the scanner," said LeBlanc. "We were moving." The fieldwork took place from June 24 through July 31, almost six weeks of intense activity supported by a rotating crew of four to eight Fenstermaker staff.

There were on-the-ground realities that only a project like this reveal. Summer is when custodial crews wax floors; timing mattered to avoid reflective surfaces and slippery hazards. Some campuses were in mid-construction, with temporary barriers and evolving floor plans. Law enforcement training exercises occasionally occupied wings that had to be avoided and then revisited. The team's answer to every challenge was the same: communicate early, adjust quickly, and keep scanning.

From rich 3D to operational 2D that saves minutes

At first glance, a colorized point cloud of a gymnasium is a thing of beauty: rafters, bleachers, basketball standards, and exit signs captured as a textured, navigable world. But crisis operations demand something different. Dispatchers need a 2D map with room polygons, labeled doors, external windows, and exits that an officer can interpret in a heartbeat. Fenstermaker designed a data pipeline that honored both the richness of 3D capture and the practical necessities of dispatchable 2D.

The workflow began with acquisition on the TrueView GO, which produced an RGB point cloud straight off the device for immediate visualization and quality assurance. Data was then processed in LP360 Land, to extract all the geospatial information from the sensor into a digital point cloud. The team used Autodesk ReCap to produce RCP files, then drafted walls, windows, and doors in Autodesk Revit, where geometric fidelity could be married to an indoor schema. From there, they exported to ArcGIS Pro and Esri Indoors, applying a structure that emphasized the elements responders use most: room boundaries and IDs, corridor geometry, door and window locations.

Standardization makes mutual aid possible. When a call triggers a multi-agency response, officers from outside the parish don't have to puzzle through unfamiliar campus code names or guess

The complete TrueView GO point cloud from one of Lafayette parish's schools loaded into GeoCue's LP360 Land software, where processing begins for the indoor mapping workflow.

at the difference between "North Wing" and "Science Hall." They're looking at the same symbology, searching the same field names, and being routed to the same dispatchable locations as everyone else.

The indoor maps emphasize the small set of details that shave minutes off response times. "One of my passions is automation," LeBlanc said. "How do we quickly extract 2D maps from point clouds? How do we make this faster without sacrificing accuracy? That's where we're headed." Even as the first wave of deliverables went live in CAD, Fenstermaker was already exploring ways to reduce drafting time through AI-assisted feature extraction.

What "faster" sounds like on the radio

The value of indoor mapping is clearest when you imagine how it plays out over the radio during a crisis. Picture this: a threat is made against a high school, and within minutes law enforcement units from multiple agencies are rushing to the scene. Many of those officers come from outside the parish. They're brave

and ready to act, but they don't know the building. They can't tell the cafeteria from the auxiliary gym, or whether Room 214 is in the north wing or the south corridor.

Without detailed maps, incident command may have to rely on staging

A complete 2D view of a fully mapped school from the Lafayette project, color-coded and organized for quick, intuitive navigation by emergency responders. The enlarged area shows the room numbers and descriptors captured for the classrooms, halls and common areas. These are essential to save responders precious time.

everyone at the main entrance, leaving responders to guess their way through unfamiliar hallways. But with indoor maps integrated into the CAD system, the story changes. Command can track room-by-room clearing in real time, and dispatch can direct units straight to a named location. Instead of responders storming inside to figure it out, the radio call becomes precise: "Unit 12, proceed to Room 214, south corridor. Use Door S-3."

A medical emergency tells the same story at a different scale. Imagine a student experiencing a severe allergic reaction in an elementary

school classroom on the far side of the building, near to a service driveway. In the old pattern, responders might charge through the main entrance, lugging gear down a maze of hallways while dispatch tries to reconcile a caller's description with a decades-old floor plan. With dispatchable indoor maps, the responding crew is directed to the closest exterior door and then a left-right-left sequence to the correct room. They lift less weight, travel fewer steps, and arrive faster. In emergency medicine and in school safety, time is the metric that matters.

"The whole goal is to get our first responders in there as quickly as possible," said Maj. Kevin Savant of the Lafayette Parish Sheriff's Office. "We're giving every responder real-time information that's fresh and updated." Lt. Brad Robin of the Lafayette Police Department underscored where operations are headed next: "Our communications division and our officers will be able to see in real time what the school looks like and where they need to respond. Next, we're bringing in one of our camera systems to provide reality capture of the infrastructure to better aid in response and awareness."

A mandate meets a model

Act 425, the "Protect Our Children and Response Act" requires advance emergency mapping for all Louisiana public schools, coordinated by the State Board of Elementary and Secondary Education and the Department of Education in partnership with the Louisiana Center for Safe Schools. Lafayette Parish didn't wait for the ink to dry. Work began before the law passed, and the parish's results now set a credible standard for implementation across the state. The collaboration between LPSS, Lafayette

911, and Fenstermaker demonstrates that such projects can move at the speed of summer break when the scope is clear and the tools fit the task.

The project's momentum is already expanding. With public schools mapped and integrated into 911, Lafayette 911 has prioritized bringing in charter and parochial schools. Other parishes are evaluating the model. The same principles - quick-capture, standardization, and integration - apply beyond education. Hospitals, courthouses, jails, and manufacturing facilities are natural candidates, with appropriate privacy controls and governance. "Indoor mapping becomes an extremely valuable tool when you have agencies which are not familiar with area schools but need to be," LeBlanc observed. "This affects law enforcement, EMS, and fire. Everybody needs to work from the same map."

The distributor's role: enablement at the speed of public safety

Big projects turn on small, fast actions. When Lafayette 911 compressed the schedule, Fenstermaker's plan depended on immediate access to suitable equipment and rapid, practical training. That's where NEI showed its value as a complete solutions provider: hardware arrived, hands-on instruction happened the same week, and crews were scanning the next day.

"Fenstermaker is truly setting the standard for how schools can and should be mapped, and the TrueView GO is the perfect entry point for that work," said Mark Forsyth, Director of Sales at NEI. "We're seeing projects like this become more common as communities recognize the importance of digital preparedness. Starting at only $25,550, the TrueView

GO handheld scanner is lightweight, easy to use, and, with its SLAM capabilities, ideal for collecting accurate data indoors. It's the right tool at the right time to help agencies and engineering firms deliver safer, smarter outcomes."

William Poché agrees. "I want to congratulate Coy and his colleagues on the incredible success of this program. They chose the right technology for the job, and it shows in the results. Our partnership with Fenstermaker goes back more than a decade, and we are delighted to work alongside firms which are not only advancing geospatial innovation but also making such a meaningful difference in the safety and preparedness of our community," he said.

Why a handheld SLAM system is the right tool

Indoor school safety maps demand full coverage of the building: narrow corridors, stair towers, classrooms with lab benches and fixed casework, storage closets, administrative offices with irregular geometry, libraries, and cafeterias. A tripod scanner can do this work, but with heavy operational overhead: setup time leads to less efficient workflows.

In contrast, a handheld SLAM system such as TrueView GO is built for interior capture. Technicians can acquire a typical classroom in about a minute, sweep a hallway in a pass, and stitch those movements into a cohesive, colorized point cloud. The learning curve is shallow: Fenstermaker's team went from half-day training to production scanning in 24 hours.

"For indoor reality capture at the speed school districts need, TrueView GO hits the sweet spot," said Miles Kelly, Business Development Manager at GeoCue. "It's

lightweight, easy to use, and powered by SLAM so teams can move room-to-room without GNSS and still deliver accurate, colorized point clouds."

Color matters. In the office, RGB accelerates drafting in Revit and QA in ReCap; in the field, it aids technicians as crews confirm coverage. Even more important is that, after drafting, the data becomes a consistently labeled, searchable indoor map that CAD recognizes, and dispatchers can query without guesswork.

Lessons learned in the hallways

The Lafayette project offered a set of practical insights any district or A/E firm can reuse without reinventing the playbook. Coordinate early with janitorial and construction schedules; waxed floors and renovation barriers are real factors, and timing around them is both a safety and a data-quality consideration. Capture the canonical room ID at the source by photographing door nameplates; "Mrs. Smith's room" is fine for yearbooks but not for dispatch. Keep people out of scans. Use exterior and corridor targets and re-traverse them. Draft what responders need most and resist clutter: geometry, IDs, doors, exits, windows, and common names for navigation safe critical time. And invest in automation thoughtfully. AI-assisted extraction can shrink drafting hours without sacrificing the interpretability that responders rely on.

The team's discipline was matched by its sense of proportion. Not every project needs a photorealistic 3D twin for immediate operations. Fenstermaker continues to produce full 3D models for clients who need asset management or architectural planning, and the firm demonstrated a beautifully detailed 3D model of David Thibodaux STEM Academy as part of its early work. For emergency response,

however, the product that matters is a 2D indoor map that is standardized and dispatchable, resident in CAD and capable of being routed to devices. Meeting these requirements changes outcomes.

Protecting sensitive information while communicating success

The Lafayette partners, LPSS, Lafayette 911, and Fenstermaker, took a conservative approach to information governance. The public deserves to know that schools are being mapped and that first responders have the tools they need. At the same time, the operational details of building interiors are shared only with authorized agencies. Imagery for public communications is carefully curated and reviewed to ensure no sensitive layouts are exposed.

This balance, between transparency about the existence of capability and discretion about its details, is increasingly the norm in school safety. It builds community trust while protecting the integrity of response plans.

From parish initiative to repeatable blueprint

Lafayette's accomplishments are more than a compelling case study: they constitute a reproducible blueprint. Start with governance: bring 911, district leadership, school resource officers, facilities, and IT together to set scope, nomenclature conventions, and privacy rules. Choose the right capture modality for interiors at scale; handheld SLAM shifts the bottleneck from equipment to coordination, which is where it belongs. Plan the route through each campus with access in mind. Automate where it saves time. Then communicate the success to boards and parents without compromising security.

LeBlanc's own professional arc mirrors the project's ambition. He started at Fenstermaker in environmental fieldwork before moving into GIS, pursued advanced degrees, and now leads a team applying AI and machine learning to real-world spatial problems. "I fell in love with spatial data," he said, recalling a formative moment at an Esri conference. The Lafayette schools project is where that passion meets purpose: a summer sprint that transformed analog vulnerability into digital readiness.

There were human moments during the project to remind the team that these are living spaces, not lab benches. A maintenance worker unexpectedly crossed a scan path, leaving a ghostly smear in the data and a gentle note to reschedule that wing. A sheriff's training exercise occupied one hallway; technicians gave them a wide berth and circled back later. The pace was relentless. "If I was out there every day with them, I probably would've had them scanning every week," LeBlanc joked. "However, clear communication and the technical advantages of the TrueView GO kept us on schedule and focused."

The bigger picture: capturing reality to coordinate response

It is tempting to think of a "digital twin" as a photorealistic, immersive 3D experience, similar to a virtual field trip. Lafayette's achievement reframes that concept for public safety. A digital twin becomes consequential when it is searchable, standardized, and present at the moment of dispatch. The workflow from TrueView GO capture to CAD-integrated indoor maps is the means to that end: faster decisions, clearer communication, and safer outcomes for students and staff.

This chain depends on fit-for-purpose technology, disciplined workflows, and responsive partners. Fenstermaker brought the design and execution. LPSS and Lafayette 911 brought the mandate and the operational need. NEI brought the solutions and training that turned a plan into a project overnight. And GeoCue brought a tool built for the hallways of real buildings and the timelines of real summers.

"TrueView GO is the ideal solution for school districts that need fast, reliable indoor reality capture," said Kelly. "The combination of LiDAR, GNSS and SLAM technology, paired with three onboard cameras makes it perfectly suited for indoor data collection." That's why Fenstermaker finished an audacious project within a compressed timescale and why other districts are taking notice. When the right people align around the right tool, the distance from idea to impact can be measured in school days, not years.

The payoff is heard in a sample of radio traffic that would have been impossible not long ago. A dispatcher keys up and says, "Unit 12, proceed to Room 214, Science Lab, south corridor. Use Door S-3." The officer hits "route," sees the same map that dispatch sees, and takes the fastest path from an exterior door to a particular room, not just a building. No time is wasted. The response becomes coordinated by design, not by improvisation.

Fenstermaker has fulfilled that promise: capture reality so that, when it matters most, responders can coordinate. The rest is iteration and scale, so that other parishes across Louisiana, under Act 425, can adopt the same approach and provide digital maps of every campus. The goal is simple: get responders in there as quickly as possible with real-time, fresh information. Lafayette's maps aren't just pictures of buildings. They're a plan for how to move through them, together, when seconds count.
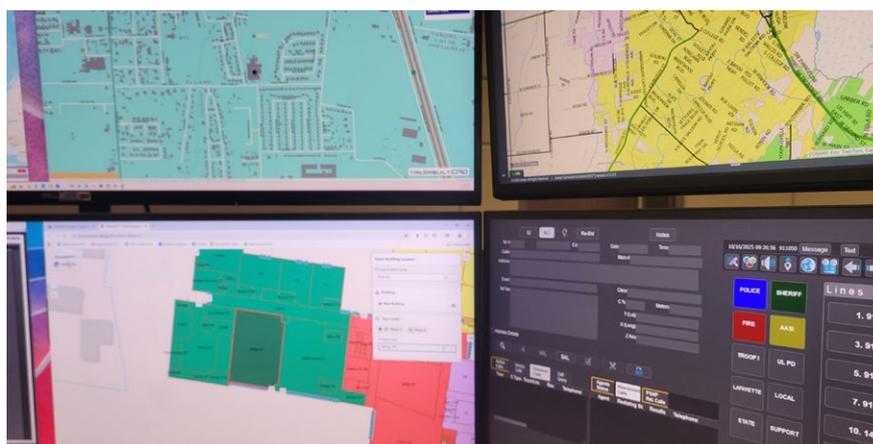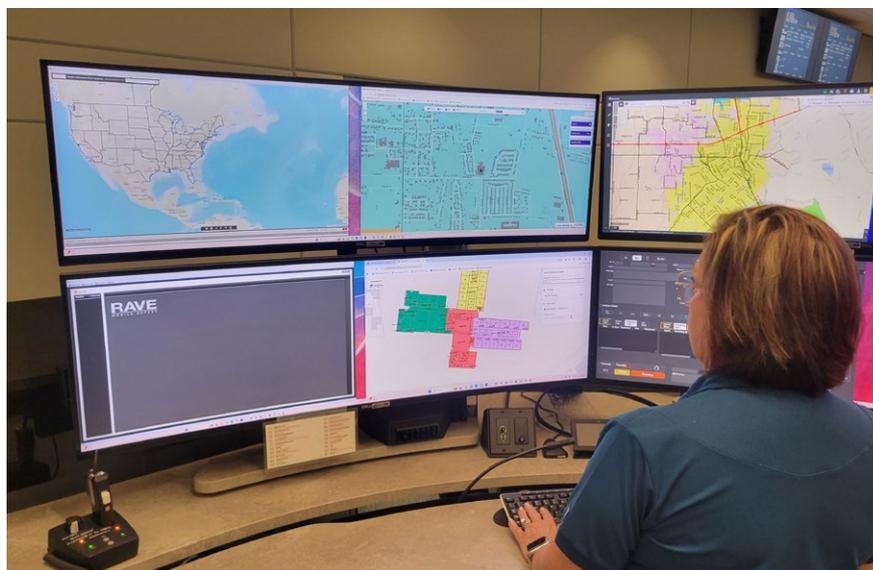
At the Lafayette 911 dispatch center, an operator reviews a fully digitized school map on her CAD workstation, part of the parish's new indoor mapping initiative for faster response. A close-up view of the digitized school map used by Lafayette 911, shows clearly labeled rooms and corridors for rapid response.

Bret Burghdurf is Marketing Director for mdGroup and has an extensive background and more than 20 years' experience in marketing, communications, creative services, and sales. At mdGroup his role is to help manage and develop the marketing platform for GeoCue, LP360 and Microdrones. In addition, he collaborates with the business development team to conceive, plan, and execute marketing initiatives to help grow the business.

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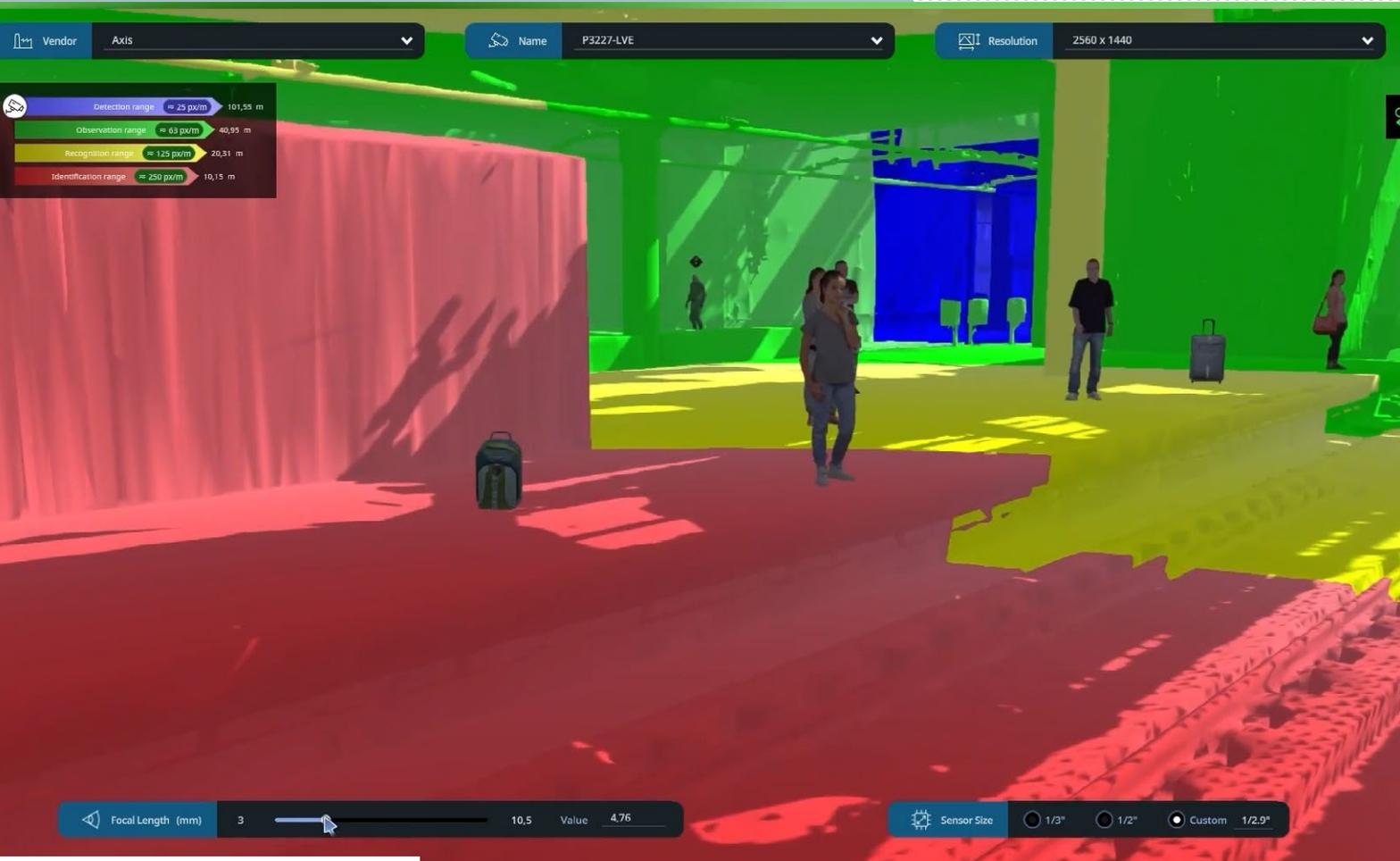
Detection of persons with HxGN dC3 LidarVision.

Lidar is setting a new standard for protecting energy grids and other critical infrastructure

BY MARTIN **VOJTEK**

For energy providers, transformer substations are an integral component of the energy grid, securely and reliably transmitting electricity to homes, businesses, schools, hospitals, etc., at the correct voltage.

Major incidents involving substations are rare. When a situation arises, however, it can cause significant problems, as was highlighted in early 2025 when a fire at a site in the UK interrupted power to 5000 homes and affected a large international airport.

Such threats, combined with the increasing demand for electricity, have authorities focusing more attention on protecting critical infrastructure.

New regulations such as the Critical Entities Resilience (CER) Directive, which will come into force across all European Union Member States in July 2026, and Germany's KRITIS Umbrella Act are being introduced to guide organizations responsible for national critical infrastructure in ensuring their resilience in the face of existing and emerging threats.

Until recently, the best practice for safeguarding unmanned substations focused on traditional forms of perimeter protection, such as fencing (typically steel, with passive infrared sensors), alarms, remote monitoring via CCTV cameras, and an access control system (often operated via a card or biometrics to manage authorized entrance).

These traditional solutions, nonetheless, have limitations. Two-dimensional cameras are less effective in poor lighting and cannot identify or track intruders once they've penetrated a perimeter.

That's where 3D volumetric detection using lidar (light, detection and ranging) technology surpasses traditional security measures.

Pilot lidar project

EG.D, part of the E.ON group, supplies electricity to 2.7 million people in the southern regions of the Czech Republic, on the borders with Austria and Germany. The company operates and maintains infrastructure, including power lines and high-voltage transformer substations.

With so much critical infrastructure at stake, EG.D decided to embark on a pioneering pilot project that would test the very latest in lidar-based 3D surveillance technology in securing substations and power lines.
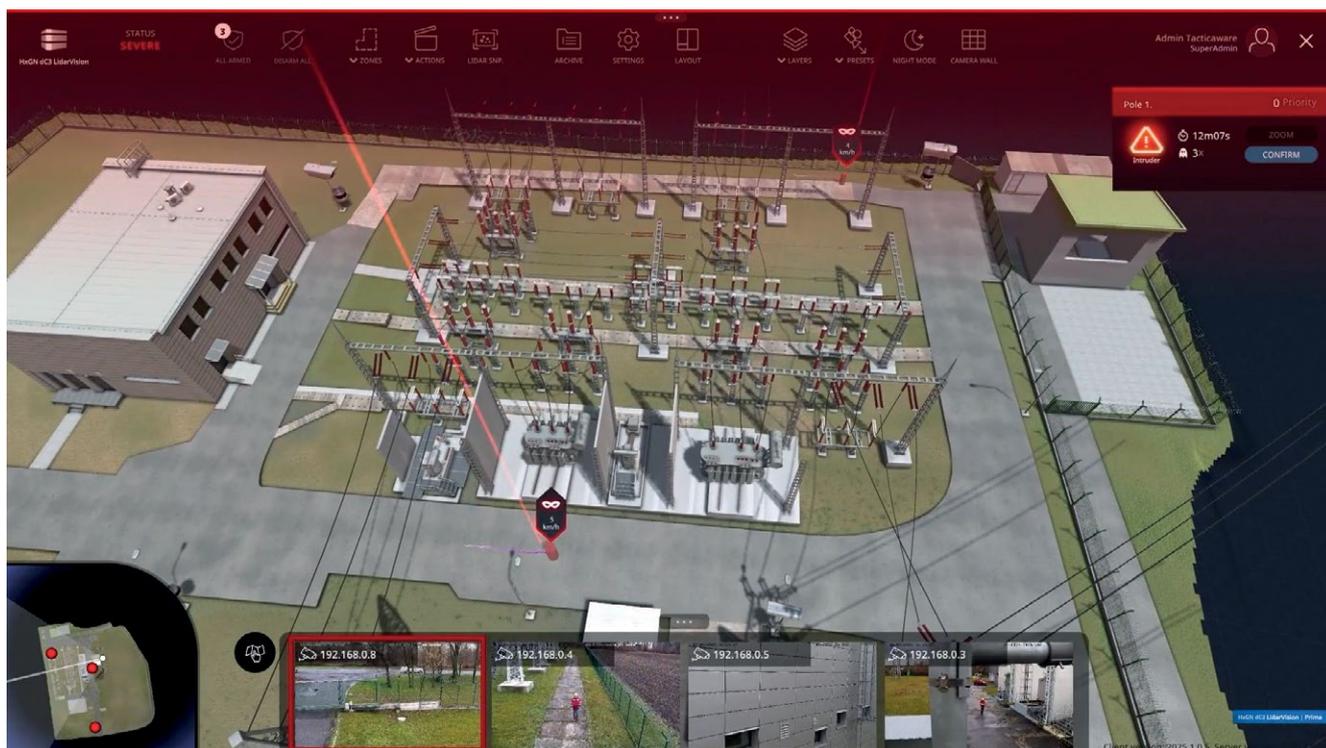
Hexagon's HxGN dC3 LidarVision in a power substation application.

Console for HxGN dC3 LidarVision.

HxGN dC3 LidarVision, part of Hexagon's dC3 physical security portfolio, was the solution chosen for the project. This advanced 3D surveillance software solution is based on volumetric detection technology and is designed to secure entire sites, unlike traditional perimeter protection systems, which tend to concentrate only on the fence line.

"We wanted to assess how the technology could be used to provide stronger security to keep unauthorized people out of substations, locate intruders and improve safeguards for maintenance personnel while they are working on-site near high-voltage equipment," said Tomáš Sofka, head of security technologies at EG.D.

Secure zones

The project uses five strategically placed lidar sensors that enable the virtual creation of secure, safe and sterile zones (including the perimeter fence). These zones can be switched on and off or changed at the click of a button or drag of a mouse. For example, when maintenance is being carried out, the zone in which the work is taking place can be deactivated. Meanwhile, other areas remain live to prevent workers from straying into an unauthorized or potentially hazardous area.

Authorized personnel and trespassers can also be automatically monitored and tracked via a live, real-time feed into EG.D's security control room. Furthermore, the system recognizes the number of people and their precise positions, along with their speeds and directions of movement (if walking or running) and even their projected trajectories. This can be augmented further with PTZ (pan, tilt, zoom) cameras, alarms and speaker systems to communicate with the person(s) in question.

Digital twin advantage

Another significant advantage of this type of system is the ability to create a digital twin for every substation. In doing so, scenarios can be played out virtually to test the resistance and resilience of safety and security measures. Essentially, this process creates a 3D representation/map of the entire facility with which users can interact. It enables the positioning of lidar sensors and cameras to be optimized to mitigate potential blind spots or poor viewing angles before anyone steps on site.

The system can be enhanced further using thermal sensors and cameras that monitor the temperature of designated areas and raise an alert if it deviates from the norm. This is valuable for intrusion detection and the early detection of fire, before it begins to smoke or ignite.

Global need

In March, the International Energy Agency (IEA) reported that global electricity consumption surged by 4.3% in 2024, driven by a wide range of factors, with increasing demand both in the home and across industry. Greater reliance on energy makes it more of a target, highlighting why critical pieces of infrastructure need to be afforded the highest level of protection.

As a result of the pilot's success, EG.D and Hexagon are working together on a plan to roll out HxGN dC3 LidarVision to other energy facilities across EG.D's grid. The company is also actively sharing its knowledge with other national energy companies, including those in the U.S. and Asia-Pacific regions, which are considering this new approach for substation resilience, safety and security.

The success of EG.D's pilot project demonstrates the transformative potential of lidar-based 3D surveillance in safeguarding critical energy infrastructure. By enhancing perimeter security, enabling real-time tracking, and leveraging digital twin technology to optimize safety measures, this innovative approach is paving the way for a more resilient and secure energy grid. ⓘ

Martin Vojtek has over 20 years of experience in security and IT. Most notably, he helped to found Tacticaware, a company known for developing Accur8vision, a lidar-based 3D surveillance solution, before it was acquired by Hexagon in 2020. He serves as Business Director for 3D Surveillance at Hexagon's Safety, Infrastructure & Geospatial division.

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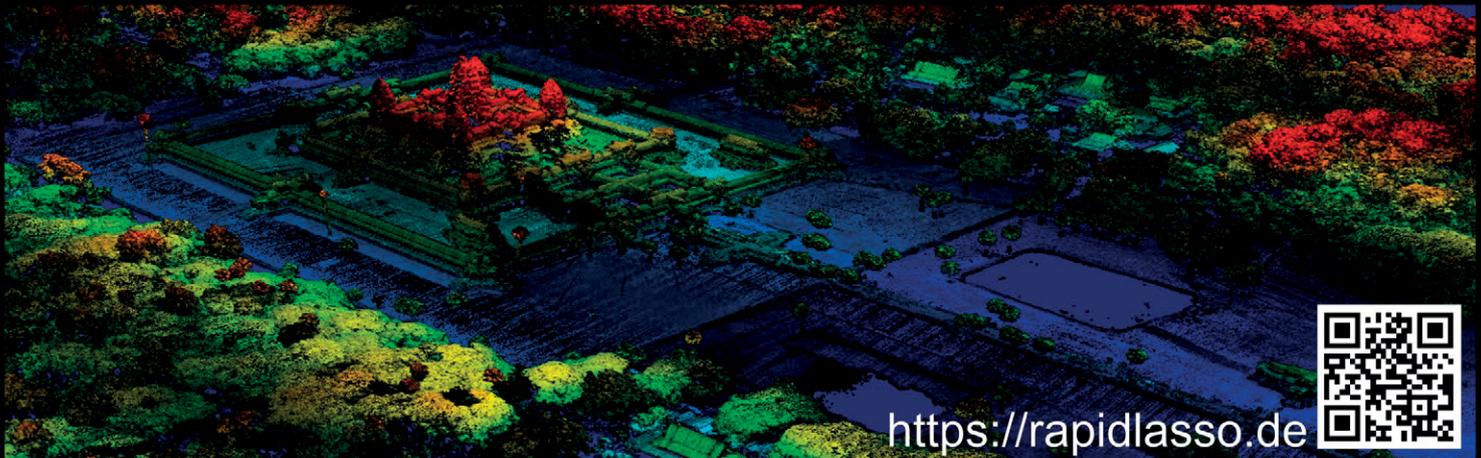
BY STEWART**WALKER**

It Is Your Game

Is felicity with the pen a characteristic of geospatial folk? We can imagine colonial survey officers scribbling erudite reports in their tents 70 years ago, or brilliant professors drafting papers today for journals with more peer-review rigor than ever. Shortly after reviewing David Maune's *25¢ Piano Lessons*, I find myself assessing *It Is Your Game* by Dr. Simon W. Musaeus, marketed as "a business strategy playbook for small business owners."[1]
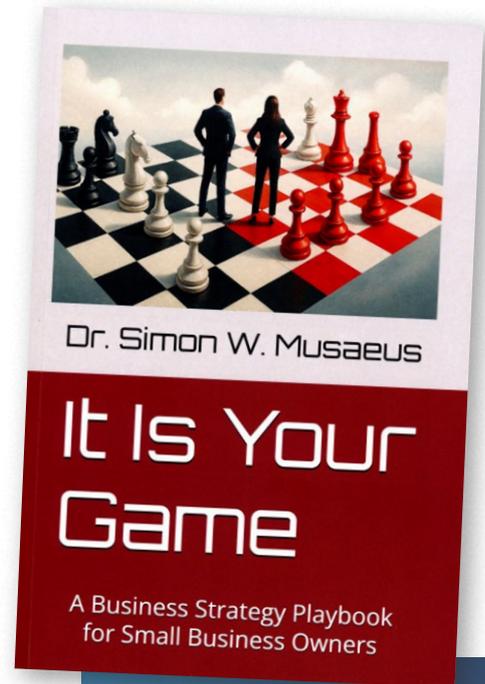
I have known Simon Musaeus for a number of years. We met first at NV5's "Acquisition Summit 4.0" customer meeting in Corvallis, Oregon, in 2019. Failure to remember names is a big weakness of mine and so it was in Musaeus's case: I tersely recorded in my meeting notes, "Remember COWI guy. DBA." I did follow up, partly because a DBA is uncommon, especially in the geospatial world. After a glittering career in the German artillery, Musaeus rose to senior vice president mapping and geoservices at COWI, a big geospatial services company near Copenhagen, Denmark, which I had visited back in my Leica days around the turn of the century. COWI's aerial survey assets were acquired in 2020 by Hexagon, where Musaeus became vice president, Geospatial Content Solutions,

steward of the firm's new geospatial content program. We kept in touch, however, and, fortuitously, Musaeus made his home for part of the year near San Diego so we were able to meet, to talk about geospatial trends and personalia, over sublime West Coast IPAs. During this period, furthermore, Musaeus was co-founder and president of the European Association of Aerial Surveying Industries (EAASI),[2] an organization set up in 2019 to represent the interests of firms using crewed aircraft for aerial survey. *Tempus fugit*, though, and Simon has moved, from America to Europe all year round and from Hexagon to consultancy. This book reflects the latter.

After a short introduction, Musaeus divides the content into five pillars, though, given his recent employment history, we may have expected six. Indeed, he omits pillar 5 from his explanation of the structure of the book. Pillar 1 is "Exploration and inventory: finding out where you are," with seven recognized techniques for this first part of the process. Each technique is described very briefly, followed by advice on how to approach it (down to the smart whiteboard). Importantly, the author assesses each technique in terms

of time intensity and complexity, as well as giving advantages, disadvantages, dos and don'ts.

Pillar 2 is "Drawing the roadmap: building your company's strategy, " has nine tools and Pillar 3, "Making it work — executing the strategy," 14 tools.

Pillar 4, "Team dynamics and decision making – success comes in groups of …," is not part of the sequence formed by the other pillars, but contains crucial information if strategies are to be created then successfully executed. The focus is on forming and leading a successful

IT IS YOUR GAME
SIMON W. MUSAEUS
- Independently published, Las Vegas, Nevada, 2025
- 225 x 151 mm, xi + 201 pp, 31 color diagrams and numerous tables
- Paperback, ISBN 979-8-280-06908-4, $32.99 from Amazon in US.

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1 Another recent contribution is Mark E. Meade's *The Bourbon Journey*, published in 2024, but the contents are out-of-scope for a review in *LIDAR Magazine*.

2 https://www.eaasi.eu/

team, based on the Myers-Briggs Type Indicator (MBTI) personality assessment tool. The pillar is divided into three steps: the first explains MBTI in greater depth and describes how to use it for team-building; the second introduces tools that foment productive discussion while taking into account the differences between the team members; the third suggests how to resolve biases and other inconveniences. I was pleased to see the Abilene paradox get an airing here, remembering it from one of my own management training experiences.

The book ends with Pillar 5, "Your brace: an ultimate fast track for the desperate owner." Musaeus admits that it is a little anomalous — does it belong at the end or the beginning? The chapter addresses the leader who has "no time for anything." It seeks to provide help to go beyond panic and inactivity to useful progress. Musaeus's description of the slough of despond is captivating. The "rapid response toolkit" offers five tools, followed by a paragraph about balancing speed and strategy. Thus the book ends strongly by becoming significantly more applicable.

The book is intense: containing numerous short summaries of established techniques, it requires concentration and is best read a few pages at a time. Most of the techniques are widely available in business textbooks, but Musaeus collects a remarkable number in a manageably short volume. Initialisms are commonplace and at one point I thought the book was talking about subject-matter experts (SMEs), when the text reminded me - small- and medium-sized enterprises!

There are two appendices. The first is about setting up meetings, an unpleasant chore for many of us and doubtless

returning to the fore as attendance at the office becomes increasingly mandatory. The second is about intellectual property — detailed acknowledgements of the author's sources and hints on using the tools.

There is no doubt about the intelligence and competence of the author. Moreover, as one would expect from a DBA, he is well read and provides a useful bibliography, wisely restricted to 27 items, many of them much cited, such as Porter's 1979 paper on competitive forces[3].

It's interesting that Musaeus gives fulsome acknowledgement to several close acquaintances, several of whom are involved in EAASI. One of them is Rachel Tidmarsh, treasurer of EAASI and CEO of the UK geospatial services company Bluesky. Her company must have followed a successful strategy: it was attractive enough to be acquired by Woolpert earlier this year!

The book, therefore, is wide-ranging and packs an enormous amount of advice into a small space. There are useful hints on what to do and what to avoid with respect to each technique, as well as the time requirements and complexity of each. For example, Musaeus describes how each tool can be used rapidly by the CEO and one or two senior managers, or, if more time is available, in a larger charette. Thus he goes beyond summaries that make established approaches more accessible, through assessment of their practical implementation and value. Furthermore, he often makes suggestions as to which tool(s) to use before and after the one under discussion. Even more useful are

his "Great Tip" boxes, which are used to give advice that one suspects comes straight from his own experience.

Having participated in numerous strategy meetings and workshops, I wish I had had Museaus at my side to provide guidance. He knows multiple tools intimately, whereas in my experience we often had only one, which the meeting leader assured us was the greatest thing since sliced bread. That's not the case here. On the other hand, while we often had good data on our own sales, for example geography, market segment and price points, we had rather less on our competitors, though we did have detailed technical comparisons of our products against theirs. Nevertheless, I worry that Musaeus assumes that SMEs have more hard data at their fingertips than they really do. How many of the tools work without it? Sensitivity analysis, for example, is vulnerable to poor data. Musaeus often warns against using the tools with only assumptions, but in practice there may not be anything better. Strategizing is tough!

For this reviewer, however, and, I surmise, many readers, the book begs for case studies, or at least examples of the application, success or failure of techniques in practice. Hexagon is much too big to be a candidate, as is the German military, but Musaeus has enormous experience of customers of all sizes and has discussed with them their pain points. Indeed, EAASI's very focus is the amelioration thereof. Surely he can compose some short case studies of strategic decisions made by small- and medium-sized geospatial firms? How did they reach their strategies and did they succeed? This book is well worth having, but we are gasping for a sequel to *It Is Your Game.* ▪

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3   Porter, M.E., 1979. How competitive forces shape strategy, *Harvard Business Review*, 57(2): 137-145.

Management deployed CAP immediately following Hurricanes Debby, Helene and Milton to survey the areas where the hurricanes made landfall. This imagery is critical for identifying stranded homeowners and finding emergency evacuation routes.

- **Lidar and sonar quick scans:** If it can be acquired, preliminary airborne lidar can be used to map terrain changes or debris piles in accessible areas. In the case of coastal storms, bathymetric sonar surveys of harbors and channels are conducted to ensure safety of navigation. After Hurricane Milton struck Florida in 2024, Port Tampa Bay—the state's largest port—was closed owing to potential underwater hazards. NOAA's Office of Coast Survey, the U.S. Coast Guard, and the U.S. Army Corps of Engineers (USACE) teamed up with Woolpert to perform an emergency multibeam sonar survey of the ship channel. Working overnight, the Woolpert survey team mapped the seafloor and confirmed that no shoaling or large debris were obstructing the channel. Thanks to this rapid mapping, *Port Tampa Bay was able to reopen just three days after the hurricane,* allowing fuel barges and relief supplies to resume flow—an outcome praised as critical for both public safety and the local economy.

Applications of immediate post-storm data

These fast-turnaround datasets are applied directly to emergency response and short-term recovery:

Woolpert completed sonar mapping of the channel leading to Port Tampa Bay after Hurricane Milton, enabling the port to be opened within three days of landfall.

- **Search and rescue:** Up-to-date maps of flooded areas guide rescuers to stranded populations.
- **Debris and damage assessment:** Officials use aerial imagery to pinpoint where debris removal or repairs are needed most, often by comparison with pre-storm images.
- **Navigation and infrastructure:** Sonar results ensure ports, shipping lanes, and bridge foundations are safe, preventing accidents as maritime and transport operations restart.

While speed is paramount (data is often collected and shared within 24-48 hours of landfall), the trade-off is that this initial data is not always survey-grade. Nevertheless, it provides an indispensable picture of the initial situation. As emergency response teams often say, these efforts help "keep eyes on" the disaster zone when traditional access is limited.

Long-term baseline mapping: preparing for tomorrow

After the immediate crisis subsides, attention shifts to establishing a new geospatial baseline. Typically, a few months after the event, once cleanup is done and waters recede, high-fidelity surveys are conducted to document the permanent changes caused by the hurricane. This data becomes the foundation for future planning and resilience.

- **Topobathymetric lidar surveys:** A flagship technique for post-storm baselining is airborne topobathymetric lidar, which uses a combination of infrared lasers (for land elevation) and green lasers (which penetrate water for bathymetry). By flying these sensors over the affected coast, we obtain a seamless 3D model of both terrain and shallow seafloor. Federal agencies such NOAA and USACE (via I-ATLAS Interagency Airborne Technologies for Lidar, Analysis, and Surveying, formerly known as JALBTCX) often fund these projects and contract private mapping firms to execute them. NGS uses the data to update the official U.S. shoreline and coastal maps. For instance, six months after a major hurricane, NGS may task industry partners to collect new lidar, which precisely captures how beaches, inlets, and floodplains have been reshaped. The result is an updated coastal dataset that serves as the "new normal" reference point.
- **Drone Lidar for Debris Estimation:** The use of drones (UAVs) to survey for debris volume estimation is becoming more prevalent for FEMA reimbursement. However, this is a topic for another discussion.

- **Example – "Superstorm" Sandy:** In one of the largest efforts of this kind, NOAA initiated the "Supplemental Sandy" mapping project. After Hurricane Sandy's destructive landfall in 2012, Dewberry, Quantum Spatial (now NV5) and Woolpert collaborated under NOAA's guidance to survey the Atlantic coast from South Carolina to New York. In 2013–14, they collected topobathymetric lidar and high-resolution imagery along ~1200 miles of shoreline. This resulted in detailed elevation models and orthoimagery of the post-Sandy coast. The data allowed NOAA to update nautical charts and coastal hazard models and provided coastal engineers and communities with a critical dataset for rebuilding. It also ensured that the impacts of any future storm in the region could be measured against a consistent post-Sandy baseline.

Why new baseline data matters

The benefits of the fresh information generated by this data are unarguable:

- **Confirmation of lasting changes:** For example, it measures how much sand a storm eroded or where new channels formed.
- **Support for better reconstruction:** Planners use the data to decide where to rebuild or bolster defenses (such as dunes or seawalls), armed with real measurements of the effects of the storm.
- **Improvement of future forecasts:** Updated models of the terrain and shoreline feed into flood prediction and simulation models, making future storm surge or inundation forecasts more accurate for the changed landscape.
- **Legal and regulatory needs:** An updated shoreline from NGS can redefine property boundaries, update flood zones, and inform environmental permitting. In essence, today's post-storm survey becomes tomorrow's "pre-storm" dataset for the next event, enabling a continuous improvement in readiness.

Public-private partnerships: a force multiplier

A persistent theme across both phases is the vital collaboration between government agencies and private geospatial firms. Major hurricane response efforts often exceed the capacity of government alone, and that's where industry steps in.

- **Rapid response:** In urgent scenarios like Port Tampa Bay after Hurricane Milton, pre-established contracts allowed NOAA to utilize Woolpert's surveyors and resources. This public-private coordination was key to capturing data and reopening the port in record time. Trust and advance planning (via contract mechanisms) meant that everyone knew their role when the storm hit, greatly speeding up the response.
- **Large-scale surveys:** For extensive post-storm projects (like the Supplemental Sandy mapping), multiple companies often join forces to support mapping requirements. The private sector brings specialized technology, extra aircraft and personnel, and expertise in data processing, while the public sector sets standards and ensures that the results serve broad public needs. The industry partnership for Sandy is a prime example of how pooling resources and know-how can achieve something that no single entity could easily do alone.
- **Innovation and efficiency:** These partnerships encourage innovation. Companies may use the latest sensors or develop new processing techniques during the project (for example, sophisticated algorithms to distinguish land and water in topobathymetric lidar data). The knowledge gained is often shared, improving practices for future events. Moreover, leveraging private firms can be cost-effective – agencies can scale up quickly after a disaster and scale down afterwards, rather than maintaining large year-round survey fleets "just in case".

Thus geospatial professionals in both government and industry form a "team of teams" when disaster strikes, each contributing to the common goal of protecting lives and accelerating recovery through data. ℹ

Amar Nayegandhi, CP, CMS, GISP is global head of technology and innovation and geospatial sector leader Woolpert. He is responsible for aligning, optimizing, integrating, and expanding Woolpert's technology portfolio across its globally integrated architecture, engineering, and geospatial platform. Amar is an ASPRS Fellow and was the director of the ASPRS Lidar Division. He co-edited the ASPRS DEM Users Manual, 3rd Edition and authored the chapters on airborne topographic lidar and airborne lidar bathymetry.

Al Karlin, Senior Geospatial Scientist, Dewberry, serves as a consultant on Florida-related lidar, topography, hydrology, and imagery projects.

Geospatial data for hurricane response and resilience

When hurricanes strike, geospatial data becomes an essential tool for both immediate disaster response and long-term coastal resilience. After a storm, two phases of mapping typically occur: one *immediately* in the aftermath to aid emergency operations, and another *months later* to establish a new baseline of the changed landscape.

Immediate post-storm mapping: a lifeline after landfall

In the days immediately following a hurricane, geospatial teams rush to collect critical data that helps authorities assess damage and safeguard communities. The focus is on speed and coverage:

- **Aerial photography:** Within hours, NOAA's National Geodetic Survey (NGS) often flies aircraft over impacted areas to capture high-resolution aerial photos. For example, after Hurricane Helene hit the Southeast U.S. in 2024, NOAA rapidly released aerial imagery of flooded neighborhoods, eroded coastlines, and damaged infrastructure. These images enabled responders to map flood extent, identify blocked roads, and estimate structural damage, without waiting for ground surveys. Such imagery also aids in spotting hazardous debris or oil spills in waterways for immediate clean-up.

Similar to NOAA, the Civil Air Patrol (CAP) plays a major role locally in mobilizing aircraft to capture emergency aerial photographs. These are generally low obliques showing the maximum impact on structures and extent of flooding. For example, in 2024, the Florida Department of Emergency

Woolpert completed sonar mapping of the channel leading to Port Tampa Bay after Hurricane Milton, enabling the port to be opened within three days of landfall.

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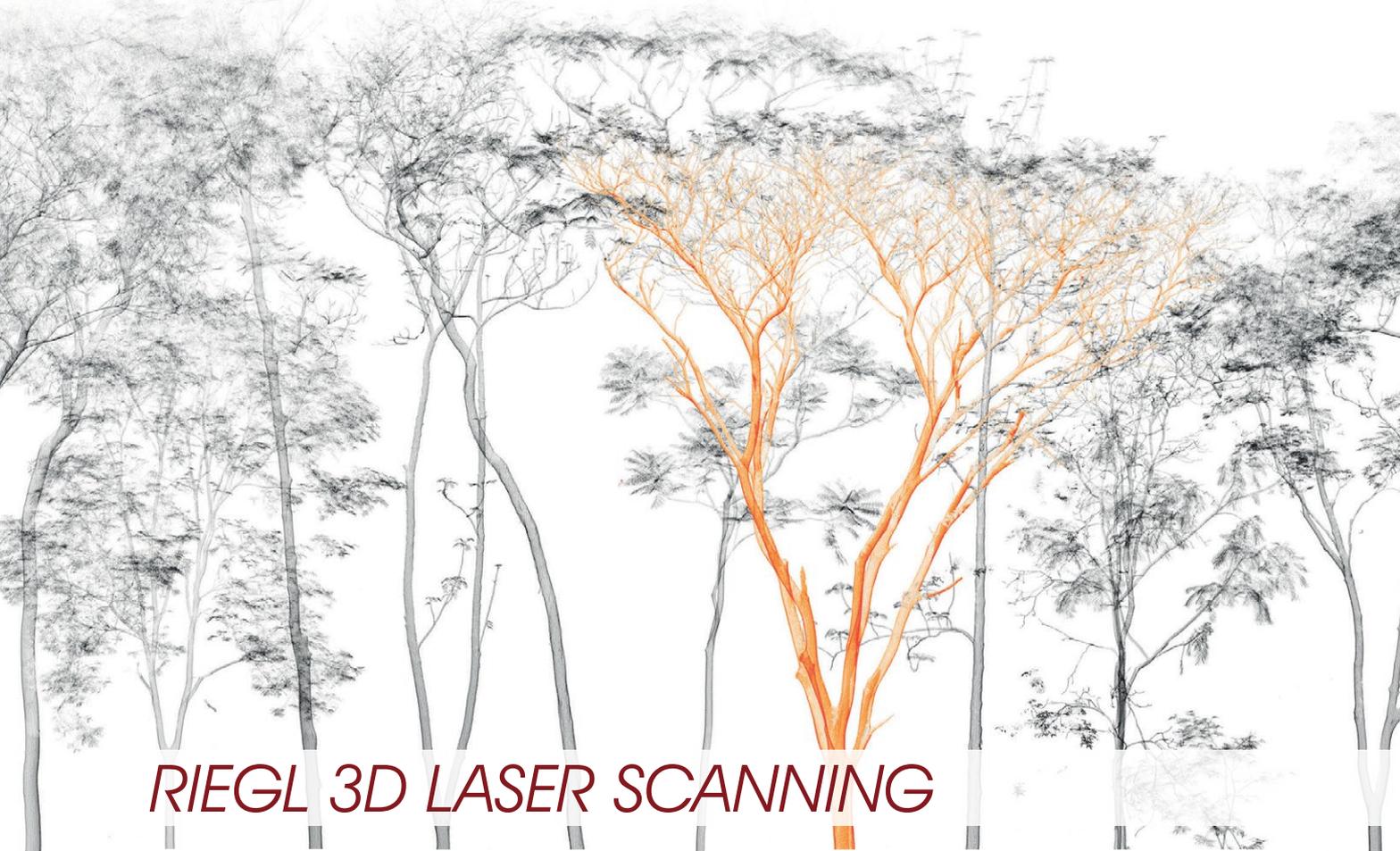Government and Education Applications.

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