VOLUME 10 ISSUE 5

# LIDAR MAGAZINE

OCT/NOV 2020

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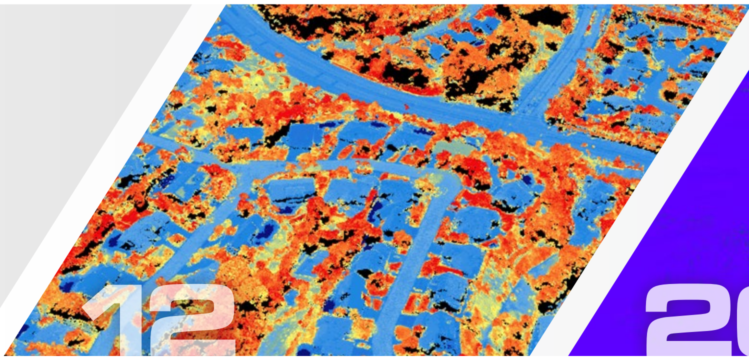
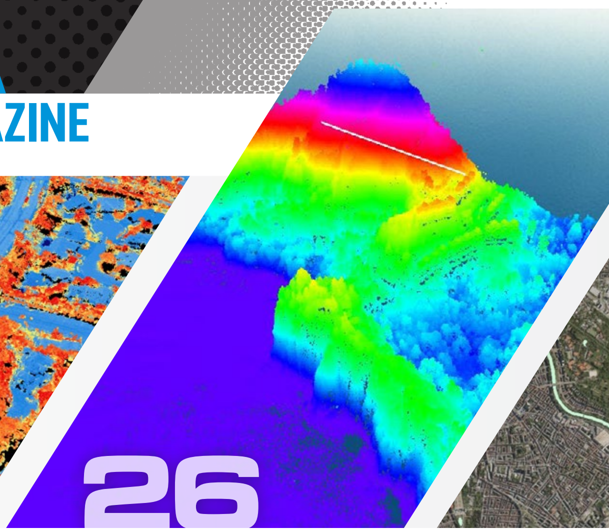
# LIDAR MAGAZINE





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Readers of LIDAR Magazine know that suppliers of lidar sensors who cater primarily to automotive customers have been making a big difference to the geospatial world, since their products are often well suited to UAV-lidar as well as MMS applications. Managing editor Stewart Walker traveled to Quanergy Systems, in Sunnyvale, California—the heart of Silicon Valley—to explore the situation in more depth with co-founder and CTO Dr. Tianyue Yu. Quanergy's relatively low price point is a factor in the adoption of UAV-lidar.
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DeepRoute.ai Ltd., which is based in Shenzen, China, with facilities in Beijing and Fremont, California, takes us further into an area that has become key for this magazine—the hardware and software necessary for lidar-equipped autonomous vehicles (AVs) to operate. We were offered a remote Q&A with a DeepRoute executive to provide a perspective on the company and its cutting-edge product, DeepRoute-Sense, the company's level 4 full-stack self-driving system, which was first introduced in October 2019 and has subsequently been further refined.
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DR. A. STEWART WALKER

# Season of Mists and Mellow Fruitfulness

It seems to have been an interminable summer, followed by a prolonged Fall. The political situation in several countries has hit severe turbulence. Covid is tenacious and loathe to recede. Climate change is not universally accepted, yet in southern California the seasons feel increasingly uncoupled from the calendar – I shop for drip-irrigation parts, as temperatures day after day top 90°F, from a Home Depot stuffed with paraphernalia for the holiday season…

*LIDAR Magazine* readers, however, have much to celebrate; despondency should not invade our technological lives. We are fresh from Apple’s announcement of the iPhone 12, complete with lidar. In the geospatial world, when costs plummet and advanced capabilities become available to vast new markets, we have coined the term “democratization”[1]. Few luminaries, however, would have had in mind, however, the abundance of Tim Cook’s devotees. What will they use it for? In the Fall 2020 issue, we featured Intel’s lidar innovations[2] and a recent announcement describes an application to measurement of packages and palettes[3]: perhaps enthusiasts need barely wait for their new devices to zip along the supply chain.

We have commented frequently on the flow of lidar advances from the automotive world to the geospatial. We covered not only Intel, but also Cepton, Schott and Velodyne in the last issue. In this one, we add DeepRoute and Quanergy. More will follow. Will all these lidar sensors from the automotive world fly on UAVs or be integrated into MMSs? Probably not, but those that do will make a difference. Yet *LIDAR Magazine*’s roots and the focus of many of its readers lie in surveying and mapping. We bring you three fascinating accounts of applications: the national mapping agency of Romania using lidar to analyze water bodies, Woolpert facing the challenges of deploying a Leica SPL100 in Hawaii, and Dewberry processing lidar data to assess changes to the

1 The classic paper of this genre, perhaps, is that of the Austrian photogrammetric genius, Franz Leberl: Leberl, F., 1991. The promise of softcopy photogrammetry, Ebner, H., Fritsch, D. and Heipke, C. (eds.), *Digital Photogrammetric Systems*, Wichmann, Karlsruhe, pp. 3-14, *https://pure.tugraz.at/ws/portalfiles/portal/2732174/158%2520-%2520The%2520Promise%2520of%2520Softcopy%2520Photogrammetry%2C%2520Wichmann%2520Verlag%2C%25201991.pdf*. A more recent contribution is: Cheves, A., 2019. Democratizing photogrammetry: quick-takes with Phillipe Simard of SimActive, Inc., *https://lidarmag.com/2019/10/31/democratizing-photogrammetry*, 31 October 2019. The theme is brought up to date in Lee, T.B., 2020, Lidar used to cost $75,000—here’s how Apple brought it to the iPhone, *https://arstechnica.com/cars/2020/10/the-technology-behind-the-iphone-lidar-may-be-coming-soon-to-cars/*, 15 October 2020.

2 Walker, A.S., 2020. Intel makes lidar too: renowned chip-maker launches low-cost lidar, *LIDAR Magazine*, 10(4): 44-47, Fall 2020.

3 *https://lidarmag.com/2020/10/13/measuring-packages-and-pallets-at-the-speed-of-light/*

LIDAR MAGAZINE
*www.lidarmag.com*

2020 Vol. 10 No. 4


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*LIDAR Magazine* is published 6x annually by Spatial Media LLC. Editorial mailing address: 7820 B Wormans Mill Road, #236 Frederick, MD 21701. Tel: (301) 620-0784; Fax: (301) 695-1538. 


BUILD THE FUTURE
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topography of Puerto Rico caused by Hurricane Maria. We're delighted also to include a description of the ASPRS LAS Working Group, which works on refining and updating the LAS format specification as users' needs evolve. Indeed, I learned from a recent teleconference that ASPRS is planning more work in the area of topobathymetric, bathymetric and underwater lidar. The assessment of DJI's new Zenmuse L1 lidar/camera in "Random Points" resonates: Lawrie Jordan's mantra, oft repeated for at least a generation, "The map of the future is an intelligent image", has an update—for some applications, the information source of the future is a colorized point cloud.

We have been blessed with numerous virtual conferences, webinars and other online fare, which offer some relief to those of us who yearn for travel and face-to-face contact. The Lidar Leader Awards were presented remotely, as were the glitzy prizes of Geospatial World. ASPRS, Esri and ISPRS ran versions of their major conferences online. A striking characteristic of these events has been the high quality and the lack of technical glitches. *LIDAR Magazine* is pursuing a number of presenters for written articles, though of course these must differ from the ones already being published in, for example, the *Annals* or *Archives* of ISPRS. Most recently, we have enjoyed the very professionally mounted and marketed remote version of Intergeo. We are still trying to absorb the host of product announcements and other news that the event fomented. ASPRS works regionally too: its Florida Region offered a one-day Fall 2020 LiDAR Workshop, complete with keynote by Jim Van Rens and presentations by several geospatial services companies, while its Pacific Southwest Region produced its 1st Annual Symposium on Remote Sensing & Wildland Fire (RS Fire 2020) in four two-hour sessions. Readers who have taken advantage of some of these while also tuning into companies' webinars about new products and applications will have enjoyed wonderful value in their home offices. We all hope for a return to normality in 2021, but we eagerly leverage these resources to stay current.

There's little space left to report gems from the popular press. Though not lidar-specific, an article on cadastral mapping reminds us of the unarguable benefit to GDP of land reform, a favorite theme of the Peruvian economist Hernando de Soto, who gave a keynote at the Esri International User Conference some years ago[4]: some countries have a long way to go. Satellite lidar and radar data from ICESat-2 and Cryosat 2, however, feature in a piece about MOSAiC, Multidisciplinary drifiting Observatory for the Study of Arctic Climate, mounted in a German icebreaker, *Polarstern*, which sailed north from Tromso, in Norway, and allowed itself to be carried along by the ice for several months[5]. In the last issue, we described how iinside was using lidar to monitor separation between people in spaces such as airports. This company has merged with CrowdVision. The market for such systems is energized by covid, of course, so it has been interesting to read an account of another system, from Amorph Systems and VANTIQ, which uses thermal cameras and lidar, in conjunction with security camera footage and data about flight information and passenger flows, to identify possible sufferers and make decisions whether to intervene, for example by closing areas suspected to be contaminated[6]. Closer to the ground, robots from Boston Dynamics are remarkable because they can walk, but one of their first missions is laser scanning of a Ford plant to create a digital twin[7]. The most amazing application of lidar we've read about recently, however, relates back to the article about Schott in the last issue. Today's large astronomical telescopes have multiple mirrors, carefully arranged so that a composite image can be obtained as if it came from a single, enormous optic. The relationships between the seven mirrors of the Giant Magellan Telescope in Chile are determined by Absolute Multiline Technology from the German firm Etalon, which uses lasers at 1532 nm to measure distances between the mirrors to 0.5 μm[8]. The results should furnish the telescope with a resolving power equal to 10x Hubble when it is completed in 2029. Astounding!

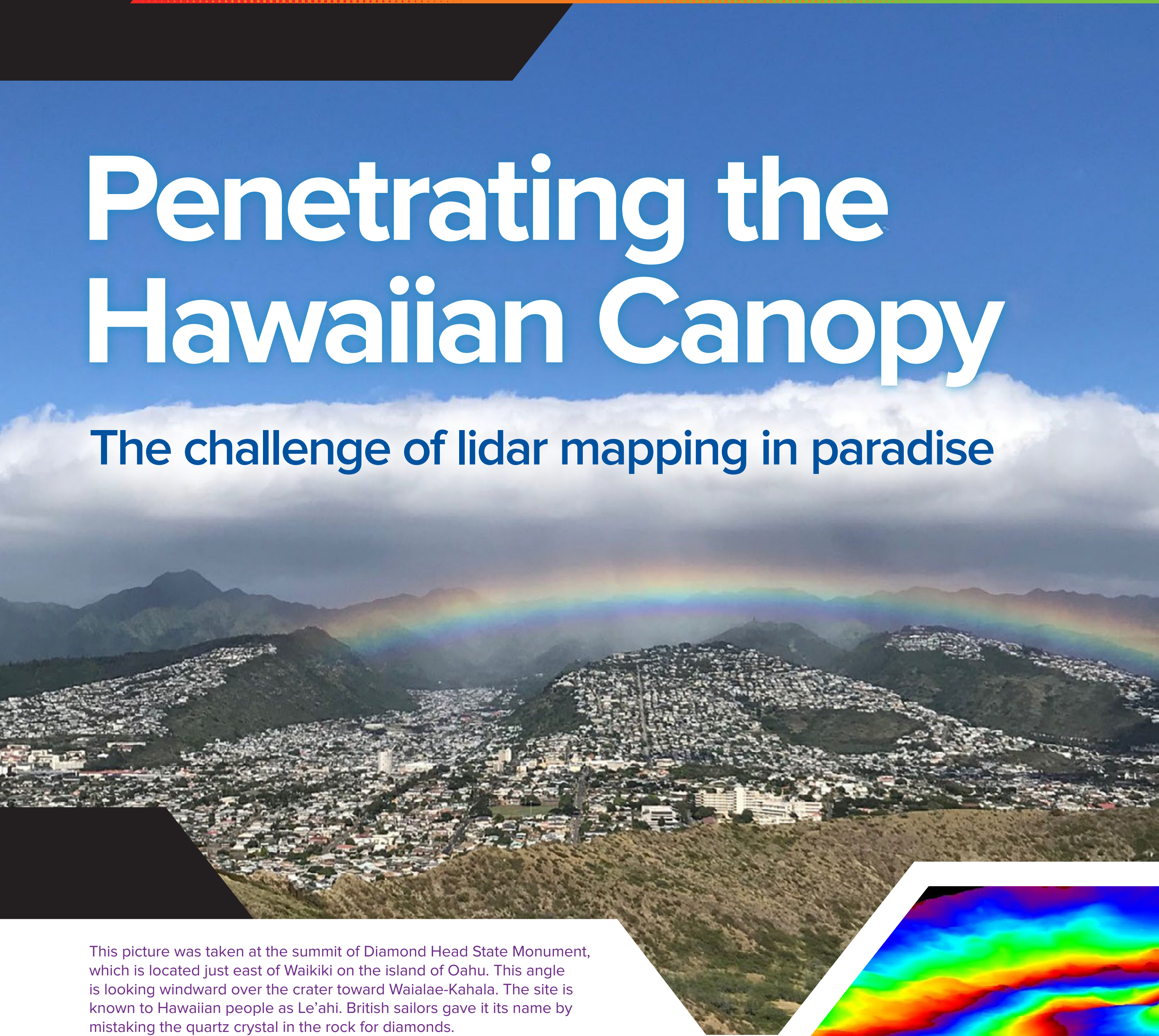
Phones, cars, maps, understanding the night sky—lidar is paramount. While scanning my files, I came upon an introduction to TLS for professional land surveyors. Compiled only 16 years ago, it described TLS as "a technique in the early stages of development"[9]. We are privileged to have experienced such profound, precipitous change. Our profession is nothing if not timely, for it surely stands upon an informational revolution.

A. Stewart Walker // Managing Editor

4 Anon, 2020. Property rights: parcels, plots and power, *The Economist*, 436(9211): 37-39, 12 September.
5 Anon, 2020. Arctic explortation: Pole position, *The Economist*, 435(9199): 68-70, 20 June.
6 Riley, R., 2020. Integrated optical system helps contain COVID-19 in airports, *Photonics Spectra*, 54(6): 18, June.
7 Anon, 2020. Automation: walking with robots, *The Economist*, 436(9209): 63-65, 29 August.
8 Coffey, V.C., 2020. The fight for first light: extremely large telescopes, *Photonics Spectra*, 54(9): 30-36, September.
9 Royal Institution of Chartered Surveyors, 2004. An introduction to terrestrial laser scanning, 6 pp.

# Penetrating the Hawaiian Canopy

## The challenge of lidar mapping in paradise

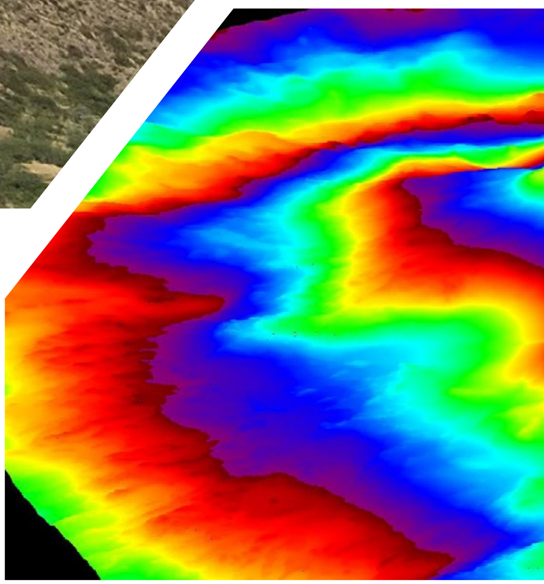


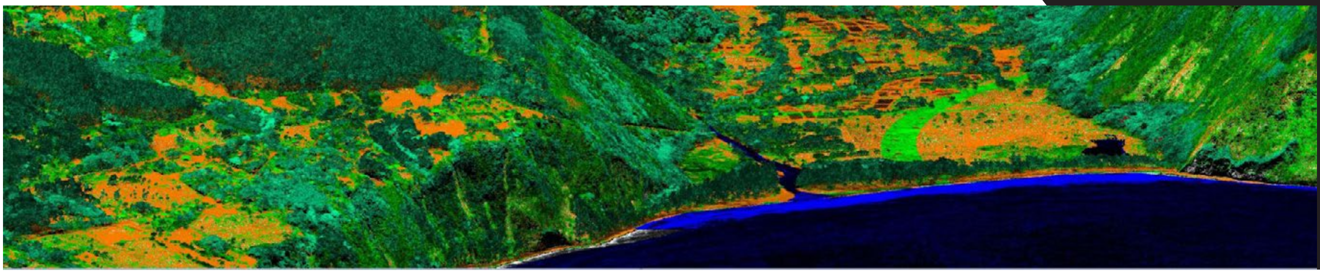
This picture was taken at the summit of Diamond Head State Monument, which is located just east of Waikiki on the island of Oahu. This angle is looking windward over the crater toward Waialae-Kahala. The site is known to Hawaiian people as Le'ahi. British sailors gave it its name by mistaking the quartz crystal in the rock for diamonds.
*Photo courtesy of Woolpert.*

After three years of planning and execution by multiple partners, most of the Big Island of Hawaii—from its steep, craggy oceanside cliffs and mountainous peaks to its lush valleys and sandy shorelines—has now been mapped using a single-photon lidar sensor. This data and imagery will be available for use by the public and to assist with everything from managing coastal issues to removing invasive species.

BY ERIC **COLE**

In 2016, the National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management (OCM) coordinated with the U.S. Geological Survey (USGS) to procure





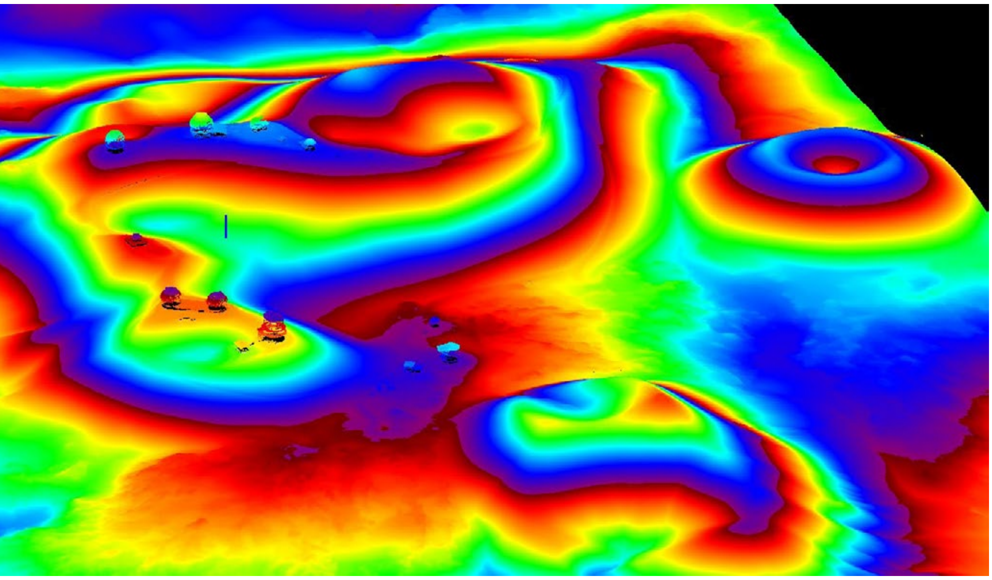
This lidar point cloud colored by classification is of the Waipi'o Valley on the north side of Hawaii's Big Island.
*Image courtesy of USGS and NOAA*

high-resolution, single-photon lidar data of the Big Island of Hawaii. NOAA OCM utilized its Coastal Geospatial Services Contract 2 and USGS utilized its Geospatial Product Services Contract 3 in a joint contract with Woolpert to acquire Quality Level 1 lidar data of the entire island. Hexagon's Geosystems division and Dynamic Aviation, which provided the lidar equipment and aircraft services respectively, supported Woolpert on these contracts.

NOAA initially was interested in collecting lidar data for a roughly 500-square-mile area in the northwestern portion of the island to perform a sediment study, but was able to leverage resources from USGS and its 3D Elevation Program (3DEP) partners to map the entire 4028 square miles of the Big Island in support of 3DEP and coastal zone management.

Ross Winans, a Pacific geospatial coordinator/senior remote sensing analyst with Lynker Technologies and on contract to NOAA OCM, said this work represents the most comprehensive lidar acquisition to date on the Big Island.

"Lidar data collection has never been done at scale in Hawaii, in terms of looking at the entire geography and comparing the data with government standards for quality control then making the information publicly available," Winans said.

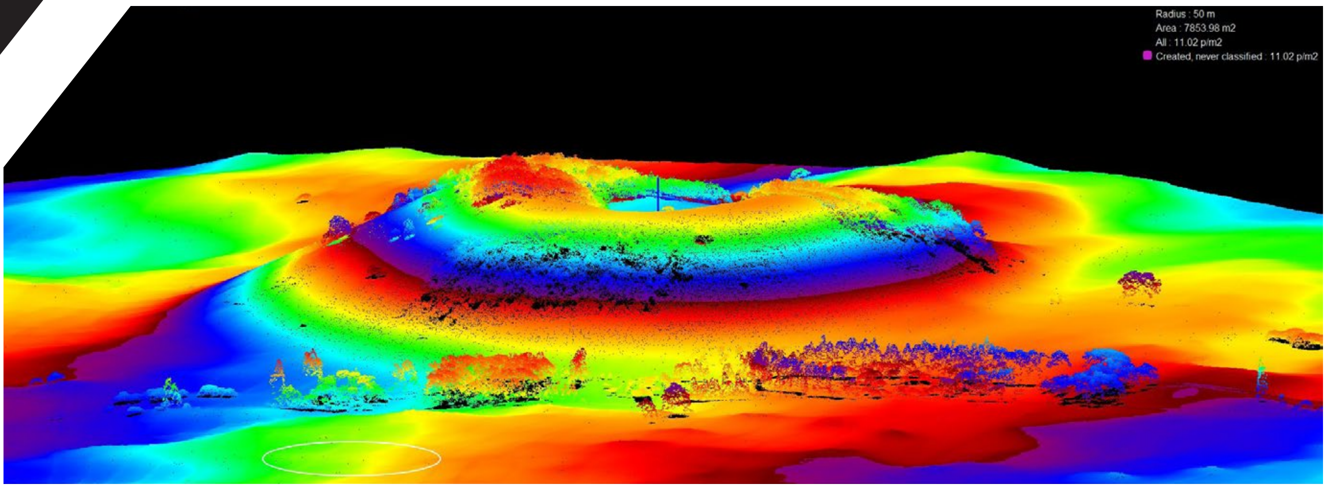


## 13-hour flights and extreme weather

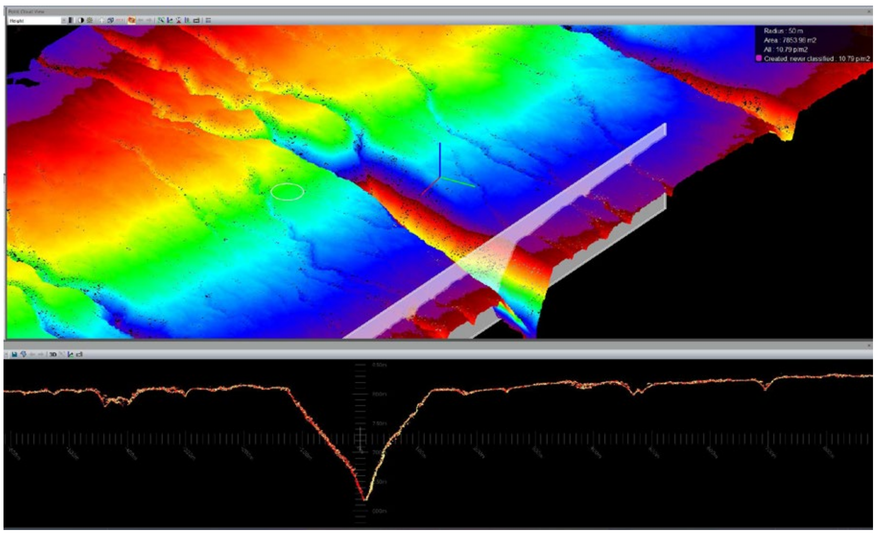
With dramatic elevation changes, dense forest canopies and disparate climatic conditions, Hawaii is one of the most geographically diverse and dynamic locations in the world. Simply getting the aircraft and equipment to the island is a costly, complicated process that requires considerable coordination and planning. Consequently, the Pacific destination is one of the most challenging locations to collect lidar data.

Extensive planning for the project began in early 2017. While a commercial airliner can fly from California to Hawaii in less than six hours, making the trip in a Beechcraft King Air twin turboprop airplane can take up to 13 hours. The aircraft must be modified with temporary, large fuel bladders to carry it across the Pacific Ocean. When the aircraft reaches the Big Island, the extra fuel bladders are removed so that the lidar equipment can be installed.

Each time the fuel bladders are added or removed, the aircraft must




Single-photon lidar data was used to create this point cloud colored by elevation of a crater on the Big Island.
*Image courtesy of USGS and NOAA.*



Point cloud colored by elevation shows a valley on the eastern coast of Hawaii, the rainiest area of the Big Island.
*Image courtesy of USGS and NOAA.*

pass inspection by the Federal Aviation Administration (FAA). Woolpert completed the contracted work in two trips over a three-year period, which equated to four inspections by FAA.

From a project management and planning standpoint, the team had to account for 10 of the world's 14 climate zones. Hawaii is the only place on Earth with so many different climates in such a small area. Consider that the northwestern portion of the state can receive 10 to 30 inches of precipitation a year, while the eastern side can be drenched by 200 inches or more. It can be snowing at the top of the dormant volcano Mauna Kea, which sits 13,796 feet above sea level, while it's sunny and pleasant along its rocky coastline base.

Hawaii also lives the effects of El Niño and La Niña cycles, which produce cloud cover that impacts when flights can be scheduled. To plan flight-time windows one to two years in advance, Winans said he consulted with Hawaii's climatologist, who was able to advise on the natural oscillation of the Earth's climate specific to this region.

"The general rule of thumb is that, during an El Niño year, there are good opportunities to collect lidar," Winans said. "During the 2018-2019 season, we experienced La Niña conditions. However, 2019's early climate indicators signaled that we could transition directly from La Niña conditions to El Niño conditions. Those would be unusual circumstances, as typically neutral conditions occur between the two patterns. We delayed lidar collection in 2019 as we waited for an El Niño that never came, and as a result we were unable to fly any missions in 2019. Eventually, we were forced to cut losses and fly during neutral conditions, which can present a major challenge on the Big Island."

The weather prevented some of the planned missions from being executed,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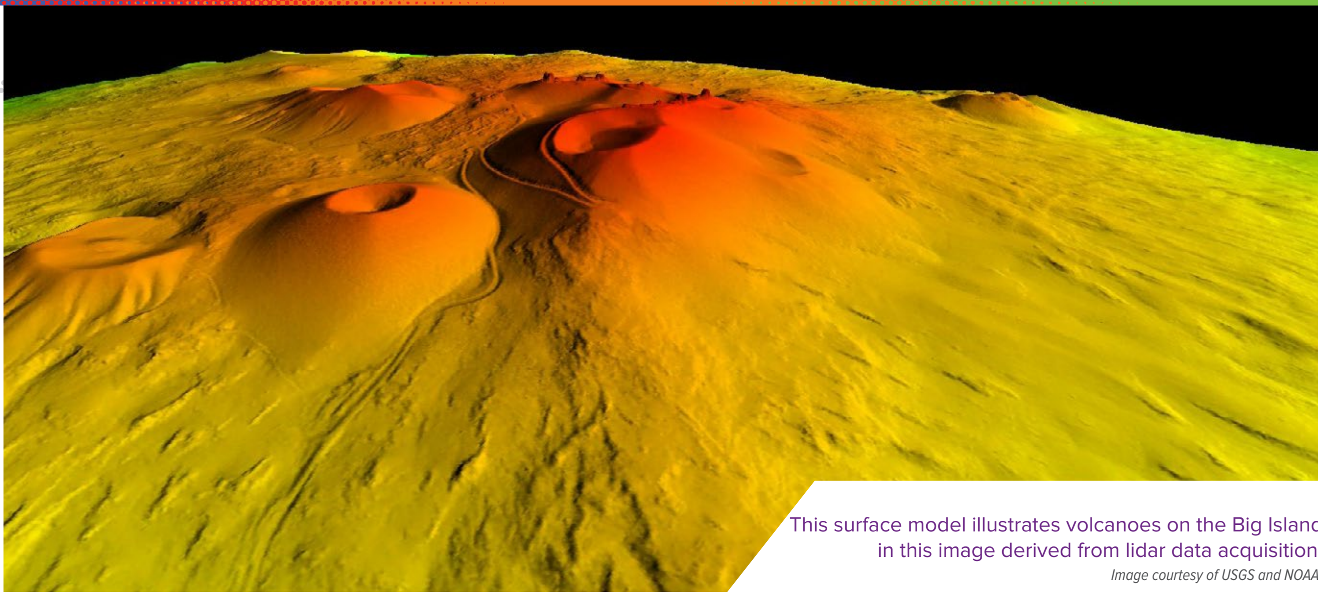


This surface model illustrates volcanoes on the Big Island in this image derived from lidar data acquisition.
*Image courtesy of USGS and NOAA.*

but about 70% of the island was covered before funding on the contract was exhausted, according to Woolpert vice president and geospatial program director John Gerhard.

"The window of time to fly missions is small, from mid-December to mid-February. Our crew was only able to fly 10 to 15 days during that time frame. The rainy, cloudy conditions prevailed, and flights occurred about once every five days," Gerhard said.

## Covering rugged terrain and dense vegetation

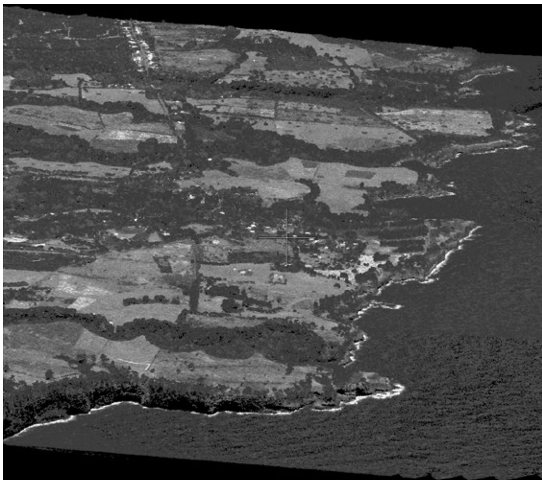
The first collections took place as scheduled between January and February 2018. The flight plan divided the island into 19 areas, based on the ground elevations above sea level. The plan enabled the crew to fly at a consistent elevation for each area. To remain within the operational limits of the Leica SPL100 sensor, altitudes were maintained between 10,500 to 14,500 feet above the terrain, depending on the flight area.

Of the 336 total flight lines that were planned, approximately 235 were executed, resulting in lidar data collections for 2819 square miles of the island.

Approximately 80 ground control points were collected by Woolpert for data calibration. Ninety-one non-vegetated vertical accuracy (NVA) points and 69 vegetated vertical accuracy (VVA) points were collected by NOAA and uniformly distributed, surveyed and later used for data accuracy verification.

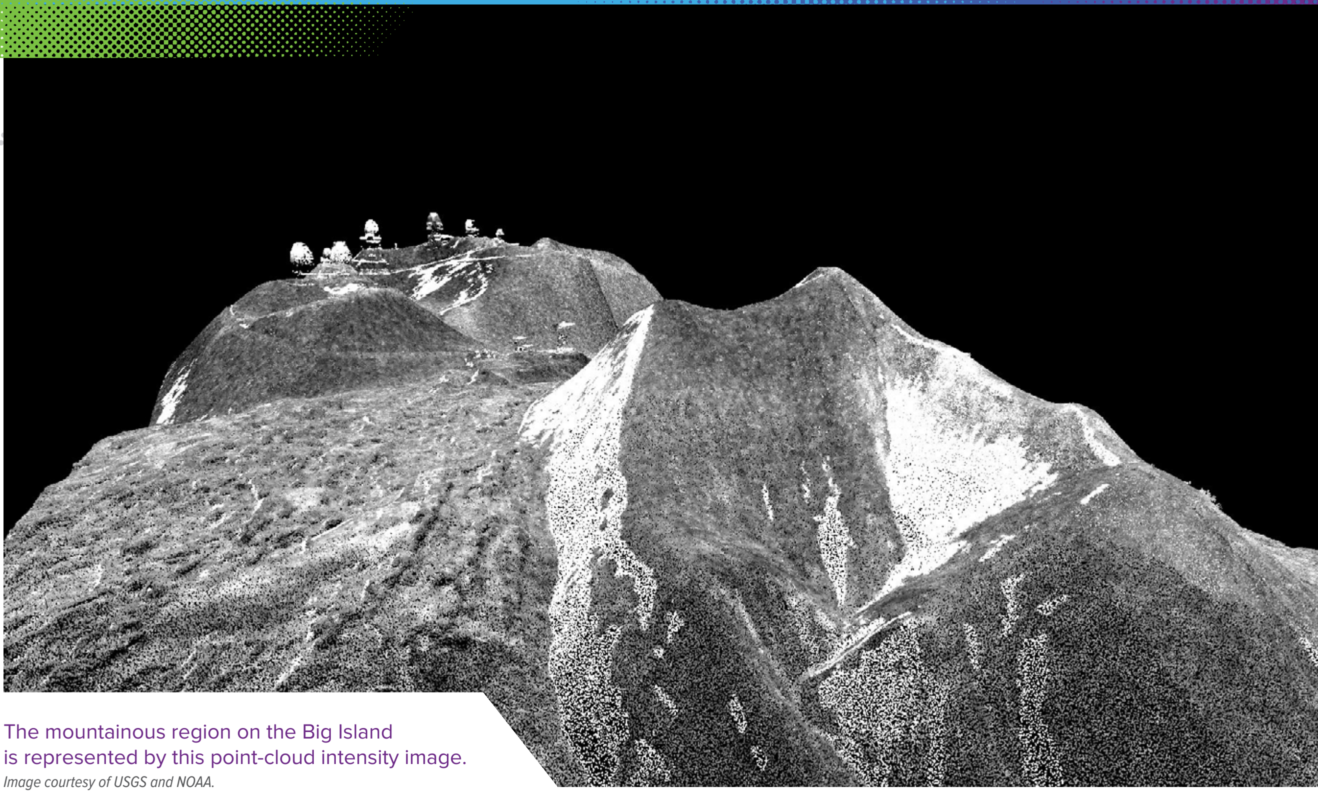
The Leica SPL100, a single-photon airborne lidar sensor, was chosen for this project instead of a linear-mode lidar sensor because of the dense vegetation on the Big Island. The system is accompanied by an 80-megapixel RGBN camera, which captures aerial imagery simultaneously with the lidar data. The sensor emits 100 output laser beams in a 10- to 30-degree swath, capturing 6 million measurements per second and collecting 12 to 30 points per square meter. While the dense canopy reduces the probability of a single laser pulse reaching the forest floor, SPL100 technology responds with a very high, first-surface point density from the 10 by 10 array of laser outputs, allowing the contract's 8 points per square meter requirement to be met.

The Leica SPL100 is up to 10 times more efficient in wide-area coverage scenarios than a linear-mode sensor, said Matt Johnson, HxGN Content Program elevation team lead and project manager.



Point-cloud intensity image, generated from single-photon lidar acquisition, depicts the northeast coast of the Big Island.
*Image courtesy of USGS and NOAA.*

"The SPL100 is best suited for high-density, large-area projects. It has been utilized in a variety of environments—high-relief mountainous areas, dense tropical jungles and leaf-on forest inventory projects," Johnson said. "For a project the size of the Big Island of Hawaii—which presents challenging terrain, difficult weather and limited collection opportunities—capitalizing on



The mountainous region on the Big Island is represented by this point-cloud intensity image.
*Image courtesy of USGS and NOAA.*

every opportunity to maximize the area captured is critical to the project success."

## Coastal management and invasive trees

Woolpert continues to process the raw lidar data and imagery into geodatabase sets and other deliverables, which will aid NOAA and USGS in coastal management decision-making, including applications such as support for local hydrologists and watershed managers, for formulating a sediment budget and identifying soil erosion hotspots.

One major application, by the state of Hawaii, is support for the removal of the invasive albizia tree, which grows across the Big Island and is found on Hawaii's satellite islands. Not only do the albizias inhibit Hawaii's native species from thriving, but the tall, brittle trees are the leading cause of property and infrastructure damage during storms. Winans said the state has a program to remove this invasive species as much as possible to prepare for and mitigate damage from tropical cyclones and other severe weather activity.

"Albizia trees grow tall above the native Hawaiian canopy, but they don't have a broad footprint when looking from above," Winans said. "With lidar, they are noticeable because they poke out of the top of the canopy. The point clouds derived from the lidar data will assist the state in identifying areas to prioritize in the program."

## Processing data, ongoing collections

The final flights to collect lidar data for the Big Island occurred in January 2020, and the data are being processed and delivered as various derivative products, such as contour maps, digital elevation models and colorized point clouds.

Woolpert is also acquiring lidar and bathymetry data over other islands in the south and central Pacific Ocean. Numerous flights have been completed or are being scheduled, including over the island of Kauai and those in the Commonwealth of the Northern Mariana Islands.

"We have been deployed in the Pacific for more than a year," Gerhard said. "We have acquired data for numerous projects at several island locations across the Pacific. We are continuing our work there while we navigate the multiple travel restrictions that are in place with various governments."

NOAA OCM geographer Dave Stein commented that these collections, like the one performed in Hawaii, will continue to prove invaluable to all involved.

"This was a multi-partner, collaborative effort that made good use of federal funding for high-quality data that will provide a baseline of information about Hawaii to be used by public and private entities for years to come," Stein said.

**Eric Cole** is photogrammetrist, geospatial project manager and senior associate at Woolpert. He is based in Atlanta, Georgia.

# LAS: What's on the Horizon

## How the LAS Working Group works

BY EVON **SILVIA**

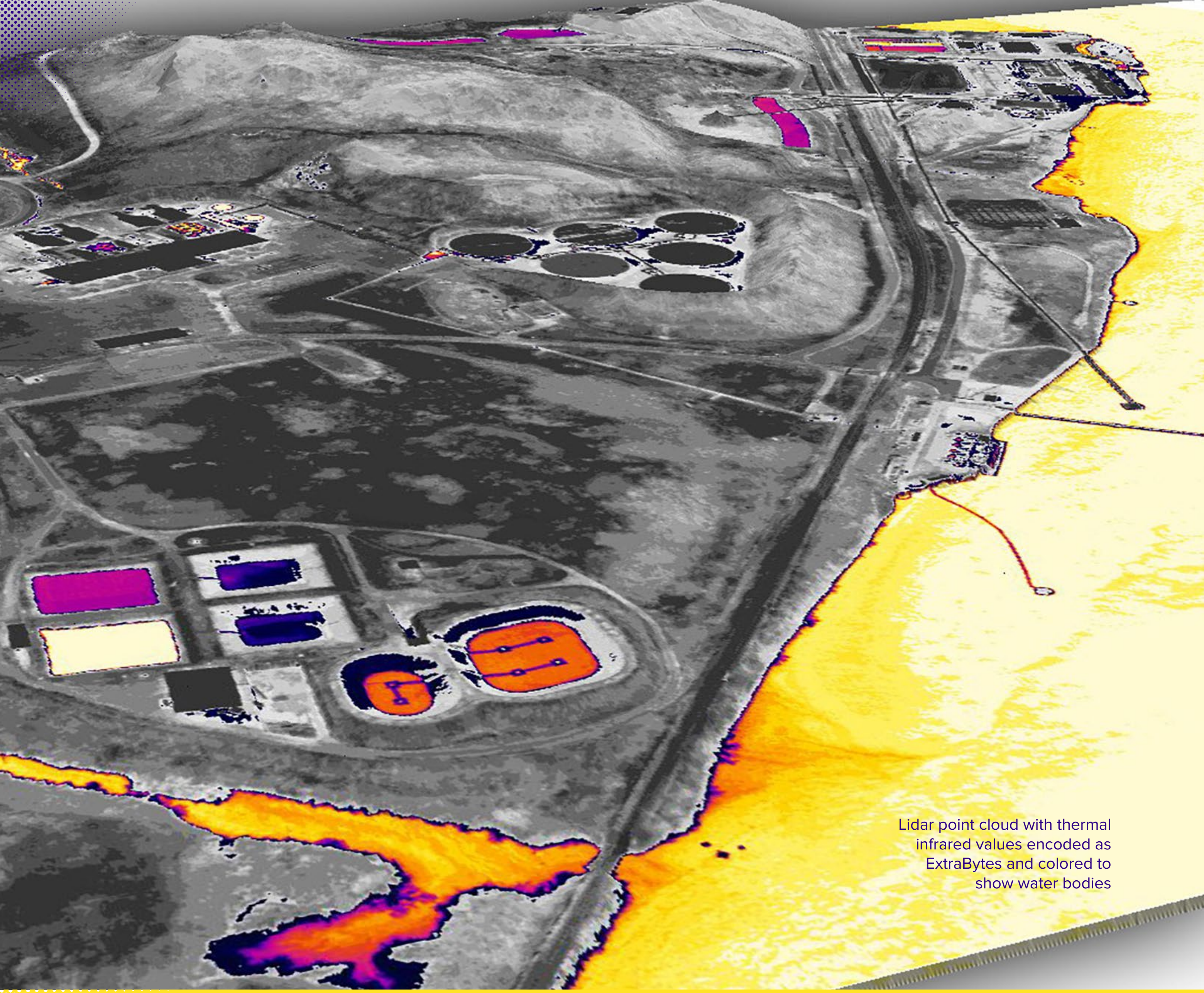
Since its introduction in 2003, the LAS file format has become the *de facto* standard format for point-cloud data, with support for it in nearly every relevant lidar software package. I'll be the first to say that LAS is not perfect by any stretch of the imagination—it has no built-in indexing system, it doesn't lend itself well to web-based streaming, and it is difficult to extend with custom attributes. Nevertheless, I believe that its widespread adoption affirms that LAS has accomplished its design objective of being a simple, compact exchange format for transferring point-cloud data between software packages.

> "Who stewards the LAS format? That's us—the American Society for Photogrammetry and Remote Sensing (ASPRS) LAS Working Group."

Yet there is still work to be done. LAS 1.4 has a great deal of untapped potential, particularly with the formalization of ExtraBytes that enabled limitless customization—for example, the graphics in this article show multiple applications of encoding imaging data directly in a point cloud. Lidar remote sensing technology continues to evolve at a rapid pace, and there is growing interest in LAS point clouds produced from sources other than lidar. LAS must evolve alongside these developments to remain useful, without compromising its mission to be a simple and compact exchange format.

But who stewards the LAS format? Well, that's us—the American Society for Photogrammetry and Remote Sensing (ASPRS)[1] LAS Working Group.

1 https://www.asprs.org/organization/what-is-asprs.html



Lidar point cloud with thermal infrared values encoded as ExtraBytes and colored to show water bodies

ASPRS is a nonprofit scientific association whose mission is “to advance knowledge and improve understanding of mapping sciences,” including lidar. Having accepted responsibility for managing the LAS specification shortly after its initial publication, ASPRS formed the LAS Working Group (LWG), which became part of the ASPRS Lidar Division[2] when it was formed in 2011. Lewis Graham led the LWG admirably for well over a decade, tackling crucial advances, such as timestamp encoding, sensor fusion, full-waveform processing, and multichannel scanners, with each iteration of LAS from version 1.0 to the current standard, LAS 1.4. Anyone interested can contribute and the LWG meets remotely every two months.

Jason Stoker, then president of the ASPRS Lidar Division, invited me to take over as chair of the LWG in 2017, an offer I eagerly accepted because I believed it would drive innovation in a way that benefited the entire geospatial industry.

2 https://www.asprs.org/divisions-committees/lidar-division

## Role of the LWG

I see the role of the LWG as straightforward and threefold:

1. Sustain the LAS specification by improving support for new applications and technologies
2. Guide changes through free, formal, public, and transparent communication channels that can provide background on all design decisions for the specification
3. Support adoption and standardization of LAS across industries

by publishing and maintaining supplemental documentation[3], tables and FAQs.

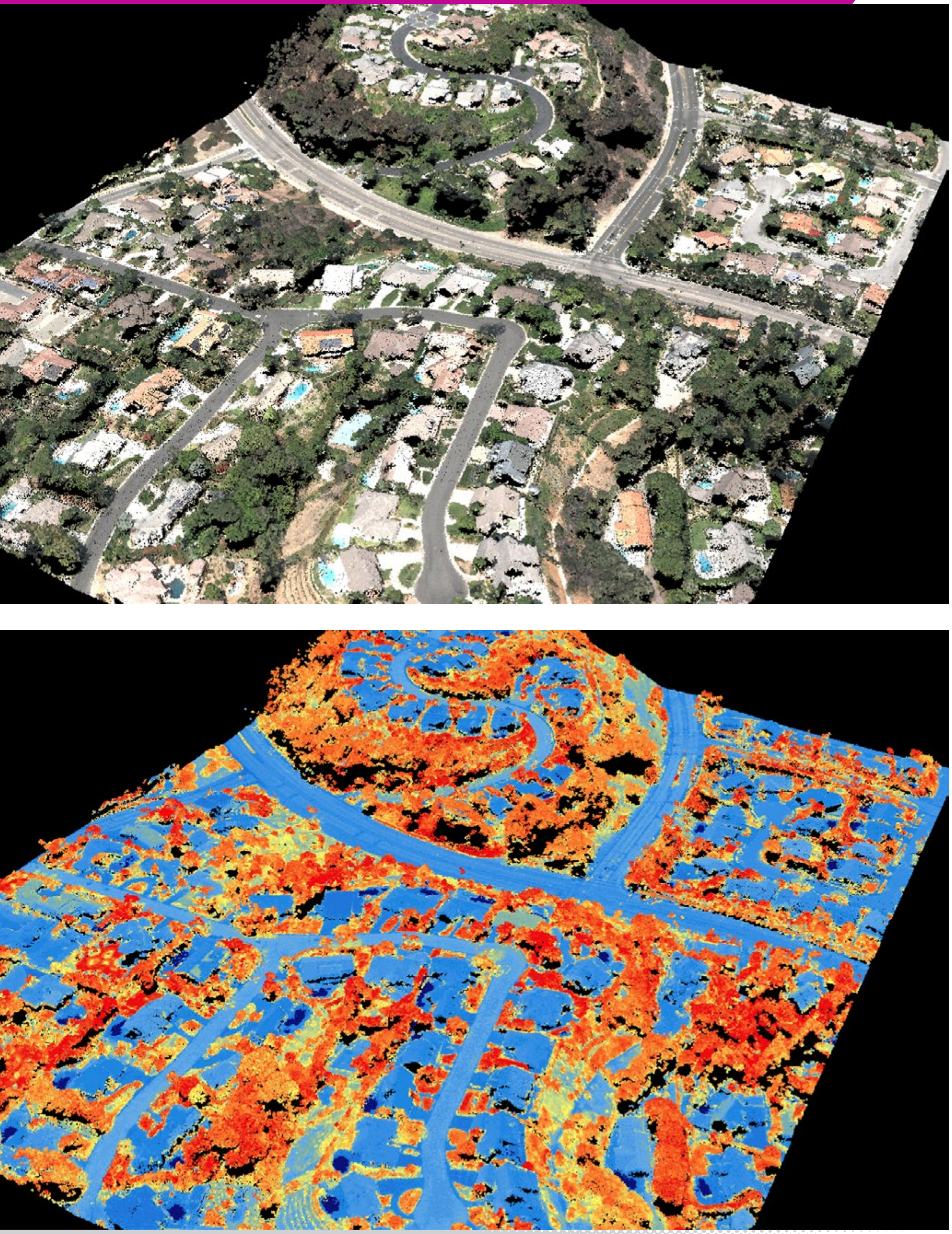
As the chair, it's my responsibility to recruit members, safeguard the specification, and foster a productive and collaborative environment within the LWG so that we can effectively exercise our responsibility to the geospatial community.

## Getting Practical

Say that you have an idea for an addition to the LAS specification. How can you contribute?

You'd begin by going to the LAS specification's Issues page on GitHub[4] and searching the open and closed Issues for a similar idea. Assuming you don't find your idea or question there, you can open a new Issue by creating one there using your free GitHub account. If you don't have and don't want an account, you can also email me at las@asprs.org with your idea and I'll create the new Issue for you.

An Issue is rather like a discussion thread on a forum. Once an Issue is created, those who are subscribed will receive an email notification, and anyone at all can provide feedback either via email or directly on GitHub. If the idea results in a potential change to the specification, a member of the LWG will create a new Branch on GitHub dedicated to your idea and assign it to a Milestone that corresponds to a future Revision or Version (more on that later). This Branch will automatically generate



By encoding 4-band image data (top) into a single point cloud, you can compute and encode NDVI directly in the point cloud (bottom), paving the way for application of decades of NDVI research to species identification and feature segmentation

3 https://github.com/ASPRSorg/LAS/wiki
4 https://github.com/ASPRSorg/LAS/issues


Encoding thermal infrared values as ExtraBytes enables discovery of gas leaks (top) or heat loss from failing insulation (bottom), directly within the 3D point cloud

a new draft of the specification, which members of the public and the LWG can comment on and revise.

Once the draft stabilizes, the changes can be submitted by anyone for inclusion in the Milestone's draft Branch (such as the draft-1.4-R16 branch[5]) via a Pull Request. Members of the LWG are automatically notified by email that a proposal is ready, and we can accept, reject, modify, or comment on the proposed changes.

Once a Milestone's queued Issues have all been resolved, the draft can go out for public comment via a Pull Request on to the specification's Master Branch[6] on GitHub. The comment period and distribution method depend on whether the new draft is a new Revision or Version of LAS.

- Revisions are minor changes to the specification itself, such as errata, typos, organization, and formatting, that improve the interpretation of the specification without impacting the format's form, meaning, or structure. No changes in a revision can negatively impact existing software.
  - Example: LAS 1.4 Revision 15[7].
- Public comment period is two weeks, or more if needed for consensus.
- ASPRS members are notified through the ASPRS Newsletter. GitHub members are notified automatically via email if subscribed. LWG members are notified through a private forum and the bimonthly meeting. Finally, I send out an email to all non-GitHub members of the public who subscribed their email address via the online form[8].

5 https://github.com/ASPRSorg/LAS/branches

6 https://github.com/ASPRSorg/LAS/branches

7 https://github.com/ASPRSorg/LAS/milestone/4?closed=1

8 https://github.com/ASPRSorg/LAS/wiki/Get-Involved

- Versions are significant changes to the file format that impact its structure, form or meaning.
    - Minor version updates (such as LAS 1.5) maintain some level of compatibility with existing software, while adding new features or functionality.
    - Major version updates (such as the short-lived and hypothetical LAS 2.0) would significantly alter the organization of the LAS file to such an extent as to break compatibility with existing software.
    - New versions are considered an entirely new specification and must conform with the ASPRS Standards Process Policy[9], including a 60-day public comment period and formal approval from the ASPRS Board of Directors.

My preference is to minimize expensive disruptions by avoiding releasing new Versions as much as possible. Instead, I tend to guide changes into Revisions, Domain Profiles, and the Wiki[10] as much as possible, and actively work with the community to come up with creative ways to improve the experience for everyone without breaking what already exists.

This approach seems to be working. In March 2019 we released LAS 1.4 R14[11], the first official modification to LAS since 2013. The full change history is available[12], but in brief we added four new standard classifications, simplified the ExtraBytes data types, clarified full waveform data descriptions (published on the wiki[13]), and added language to support technologies other than conventional linear-mode lidar scanners, such as photo-derived and Geiger-mode point clouds.

> "LAS 1.4 (R16) is underway for publication later in 2020 and awaiting your contributions. Learn more about how you can get involved."

Not afraid to admit when we make a mistake, we quickly published LAS 1.4 R15[14] in July 2019, which was largely errata from the conversion to GitHub[15].

## The Future

The next revision of LAS 1.4 (R16)[16] is already underway for publication later in 2020 and awaiting your contributions.

It does appear that we will need to create LAS 1.5[17] within the next couple of years to support the new datums from NOAA's National Geodetic Survey (NGS), which were recently delayed and are now scheduled to be released in the 2024-25 timeframe[18]. At the same time, we will probably also add a stripped-down point format that's better suited for generic point clouds for applications other than airborne lidar remote sensing, and possibly introduce a new timestamp format that resists loss of precision over time.

My goal is for the LWG to have a representative from every software vendor, hardware manufacturer, research university, data producer, and data user.

Learn more about how you can get involved[19], even if you just want the occasional email update. We'd love to have you.

**Evon Silvia, PLS,** is a solutions architect with Quantum Spatial, Inc., Corvallis, Oregon. With his diverse background in civil engineering, land surveying, sensor research, and computer programming, Evon looks at remote sensing a little differently. He has an MS in geomatics and civil engineering from Oregon State University with a focus on lidar and joined Quantum Spatial in 2011 to advance its land surveying and lidar processing divisions. As chair of the ASPRS LAS Working Group, Evon is passionate about data quality and strives to improve collaboration and communication in the remote sensing community.

9 https://www.asprs.org/a/society/committees/standards/ASPRS_Standards_Process_Policy.pdf
10 https://github.com/ASPRSorg/LAS/wiki
11 http://www.asprs.org/wp-content/uploads/2019/03/LAS_1_4_r14.pdf
12 https://github.com/ASPRSorg/LAS/pull/76
13 https://github.com/ASPRSorg/LAS/wiki/Waveform-Data-Packet-Descriptors-Explained
14 http://www.asprs.org/wp-content/uploads/2019/07/LAS_1_4_r15.pdf
15 https://github.com/ASPRSorg/LAS/pull/83
16 https://github.com/ASPRSorg/LAS/milestone/5
17 https://github.com/ASPRSorg/LAS/milestone/6
18 https://geodesy.noaa.gov/datums/newdatums/delayed-release.shtml
19 https://github.com/ASPRSorg/LAS/wiki/Get-Involved

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# Energy at Quanergy

## Silicon Valley lidar player sees markets accelerate beyond automotive

BY DR. A. STEWART **WALKER**


Quanergy's headquarters in Sunnyvale, California. The company doubled its footprint in this building during 2019.

Readers of *LIDAR Magazine* know that suppliers of lidar sensors who cater primarily to automotive customers have been making a big difference to the geospatial world, since their products are often well suited to UAV-lidar as well as MMS applications. Managing editor Stewart Walker traveled to Quanergy Systems, in Sunnyvale, California—the heart of Silicon Valley—to explore the situation in more depth. Hosted by marketing communications manager Sona Kim, he was able to talk at length to co-founder and CTO Dr. Tianyue Yu (first name pronounced T-N-U-A). Yu mentioned the partnership Quanergy had begun in 2019 with GeoCue[1], related to the use of the Quanergy M8 sensor in the GeoCue TrueView 410 product. She knew the UAV-lidar integrators well, including LiDAR USA, another customer with which Quanergy had announced a partnership[2]. Indeed, LiDAR USA had been on the Quanergy booth at the recent CES event in Las Vegas. She was familiar too with Geodetics and YellowScan. Quanergy is grateful for the inputs of the UAV-lidar integrators, which have led to product improvements. She was well aware of the strong competition on the sensor side amongst the automotive lidar suppliers, not only in mapping but also in security applications. Quanergy's relatively low price point is a factor in the adoption of UAV-lidar, since the lidar sensor is no longer the most expensive component of the integrated system, nor of systems that can easily be transferred between UAVs and land vehicles. Yu hoped the smart cities trend will be a driver of significant growth in the UAV-lidar

1 https://www.bloomberg.com/press-releases/2019-11-06/quanergy-expands-leadership-in-the-lidar-mapping-industry-by-securing-partnership-with-geocue-for-true-view-drone-system

2 https://lidarmag.com/2018/11/21/quanergy-announces-partnership-with-lidar-usa/

market. “Lidar is the best 3D device,” she exclaimed, foreseeing partnerships with players in the smart city/digital twin space, “now that we are getting more and more mature … there are a lot of synergies there.” She was conscious of their distribution channels and their capabilities in the area of 3D rendering, to which lidar could contribute so much. Mounting lidar sensors on construction equipment becomes more realistic as prices fall and the demands of the automotive market ensure reliability. UAV-lidar integrators tend to test every single system before shipping, so reliability is essential—shortcomings will be discovered! We discussed the difference between the requirements of the automotive market—to detect objects in a vehicle’s path—and mapping. Yu emphasized that Quanergy’s precision is 3 cm: the company does not aspire to millimeters at present, because its main markets don’t need this. We turned to questions submitted in advance.

**LM:** Please tell us a little about yourself. Born in China, you earned a bachelor’s degree there and proceeded to a PhD at Cornell, after which you occupied a series of high-level, high-tech positions before founding Quanergy in 2012. What guided your career choices during this period and how did it result in your entry into and subsequent staggering effect on the lidar world? How did you meet Dr. Eldada [Louay Eldada, co-founder and former CEO of Quanergy] and decide to work together? Do you perceive yourself as a technical genius, holder of multiple patents, or as a business genius, with a string of successful start-ups and divestitures, or both?
**TY:** The history part! After graduating from Cornell, my focus was in

Dr. Tianyue Yu, Quanergy’s co-founder and CEO.

nanotechnology, electronic materials and high-resolution imaging lasers. My PhD was about two-photon lithography. I was very much into lasers. I came to Silicon Valley because my husband was working here. I worked for a number of companies, in nanotechnology and high-resolution imaging, all laser-based. Louay and I worked together in another company, then we left and formed Quanergy. We followed a very structured process—when you form something new, you want to do something impactful to society, right? We do not do it out of convenience, it’s more about an end in mind, then we come back to what we could do. Healthcare, population, energy, transportation impact a society. In the end, we narrow down, see what we can do, we can’t build a Facebook. Even in 2012, the general public didn’t know about autonomous driving, yet it had been in DARPA Challenges as early as 2005. SICK and Velodyne LiDAR really benefited from those. When we founded, there was a need to dramatically lower the cost. The overall vision is that lidar is the best centimeter-accuracy 3D device to acquire this information. Cameras, radar, these compress the 3D world into 2D presentation, but lidar opens up a new dimension of context—everything’s about context—so lidar is an important piece of autonomous driving, but at the same time has uses in many other industries, but has not been fully explored yet because it was too expensive in the past. Automotive is only one of the industries we serve—that’s a differentiator. Our vision has always been to map the world in 3D. Autonomous driving is one application of that—high resolution, distance measurement, object detection, collision avoidance etc. But our vision from day one has not just been automotive, though sometimes people paint us with that brush. We set out to revolutionize society with the third dimension. This explains interaction with Autodesk, Trimble etc., which are not automotive companies, and our wish to have mapping, smart city and security products too. We just go with the flow when people see us that way [automotive], but in conversation it’s easier to explain how the platform can revolutionize many industries.

**LM:** We didn’t realize that. For the mapping world, the significance is that you have access to R&D funds from car companies, so you can produce developments and units at a lower cost that become available for mapping, which is the beneficiary. But you see it differently—you saw in 2012 that you could make a really good lidar sensor that would revolutionize many industries. That was how you got in. You obviously have enormous technical skills, but do you or Dr. Eldada see yourself as a business genius, or a technical genius, or both? That’s what Silicon Valley’s all about!
**TY:** You have to cover for both, you can’t be only on the left bench. But not just a

talking point—serious technical substance, so you are credible and have judgement. You have to have both to be good for the company and help the drive forward.

**LM:** There were incredibly able people at GeoBuiz, but they all have to get venture capital. I've heard Dr. Eldada speak and he's very good. He's compelling. Without that gift, you're not going to get the money.

**TY:** Yes, indeed. He and I went out together to the venture capitalists. Depending on the audience and the setting, sometimes I talked more, sometimes he did. I'm bilingual and he speaks Arabic and French—he's from Lebanon—so that helps. He's the CEO, often he talks more, he's the public face of the company, but I go to customer meetings and pitch there. That's a really critical capability, representing the company in that way. And sometimes they don't get to hear what they want. Those are the customers I like the most—they challenge you and they are not easy to fool! So it's extremely important to have both a business and a technical sense.

**LM:** When you look at a start-up's website, you see the glittering talent of the whole team! I've read through the details of Quanergy's leadership team. They are incredibly experienced and talented. I've noticed this characteristic in many start-ups, not just in lidar but also in space. How does it work? How do you plan your leadership team and find it? What's the key to success?

**TY:** Good question. Maybe I can answer that in reverse order. CFO Patrick Archambault became director of finance in 2016, but CFO in August 2019, a new position. He plays an important role managing the finance team. Gary Saunders joined in April 2019 as chief revenue officer, instrumental with the sales team. Enzo Signore, CMO, joined in July 2019, playing a critical role in product-market fit. Engineers can make anything, so you want to make sure you make something with the needs and the business potential behind it. These are the relatively new additions. Raj Bhullar, VP of manufacturing, joined in 2014, early on, in response to need to ramp up production. Early hires were entrepreneurially able, since they were joining a company of less than20 people. I myself was soldering, making parts etc. at that time! Why did they join? A lot of the people joined following our vision of revolutionizing the world in the third dimension. It's about photon to insight, not just mapping but the whole 3D mapping world. From lidar, you get distance and 3D information, then smart sensing solutions, enabling ubiquitous deployment worldwide. Lidar is a doorway for people-counting. That is the insight, we're not just building lidar in our team. Insights come first, then we make an impact on society. For mapping, you use a high-quality sensor. IT will be deployed in airports, e.g. to measure queues. A lot of our team members joined based on the alignment to the vision—they also believe—radar is 1D, cameras 2D, lidar 3D. The seeds grow in the different areas—3D printing and AR are 3D. If you connect the dots, these are rising above the water. Lidar is the best device to tie them together. In 2014, Google built the Tango and provided it in response to proposals, i.e. investment from Google for free. They wanted to foster a community to develop 3D software, acknowledged to be tough without big investments. Meanwhile, Apple acquired 3D-sensor maker PrimeSense in 2013 and Microsoft developed Kinect as early as 2010, having acquired 3DV Systems and Canesta *en route*. Amazon's Fire Phone, launched in 2014, was a failure, but it had a strong 3D emphasis, so is part of the same trend—the big players value 3D, so lidar matters. Everyone values it—except Elon Musk!


Quanergy M8, the firm's sensor best known in the geospatial world. The "M" originally stood for "mechanical". Quanergy emphasizes the product's low cost alongside high performance in terms of range, horizontal resolution and accuracy. Critical technical specifications include: 8 detection layers; 905 nm; range 0.5-100 m @ 80% reflectivity (M8-Ultra 200 m); range accuracy 3 cm (1σ @ 50 m); frame rate 5-30 Hz; angular resolution 0.033-0.132° depending on frame rate; FOV 360° horizontal, 20° vertical; output rate 432,000 points per second, 1 return/1.3 m, 3 returns; 900 g; 103 mm diameter, 87 mm height. The M8 is available in four models: M8 core, M8-Plus, M8-Ultra and M8-PoE+.

**LM:** The CEO of Velodyne LiDAR has just moved upstairs as chairman and replaced himself with an internal promotion. The same has happened in Trimble. That's not going to happen here yet? Will you be promoted? Any comments?

**TY:** By Series-C time, 90% of CEOs are no longer there—that's a fact in the venture investment community.

Quanergy S3 solid-state lidar sensor. Quanergy promotes S3 as a high performance, automotive-grade, smart sensing solution that is ideal for a wide variety of applications in transportation, industrial automation, security data analytics, and mapping. The economical price point enables high-volume deployment of lidar. Two models are available: S3-8 for automotive and S3-2 for non-automotive, industrial applications.

Entrepreneurs want new things—it's very natural for them to move from company to company. You will hear some news from us too! I was not surprised by your question.

**LM:** I've written a couple of articles about Cepton and I've noticed that folk here in Silicon Valley seem to jump between competing companies. Is that a good thing, i.e. is it stimulating for both the recruiters and the recruited, or is it too dangerous in terms of compromise of IP?
**TY:** Many of our team members went to Cepton and initially we were not happy. But, looking at the big picture, there is no "no compete" in California. Employees are free, though they must preserve confidentiality. I think it's good for the health of Silicon Valley—cross-pollination. You have measures of protection such as patents and copyright. Ultimately, in competition, you have to cross-pollinate yourself!

**LM:** I realize that you probably don't want, as a privately owned company, to say much about performance data, but is there anything you are able to tell me about capital raised, revenues, profitability, growth, number of employees, split of revenues amongst your different business areas (transportation, mapping, industrial automation, security), percentage of revenue invested in R&D, etc., to give readers some detail about your company?
**TY:** Yes, we're still privately held, on VC. We employ around 100 people. Revenue has grown annually and from half year to half year and we expect further growth in 2020.

**LM:** I'm from the geospatial world, so first of all I want to thank you for your wholehearted participation in this market, which must be tiny compared to your primary automotive vertical. Why are you active in the geospatial, i.e. UAV market? What's in it for you? I note that the UAV-lidar integrators are embracing your product. These are important testimonials in the UAV/geospatial world, so congratulations are in order. Do you know if anyone is using the M8 in a mobile mapping system, or even a tripod-mounted terrestrial lidar system?
**TY:** Yes, we have a number of customers with our sensors in MMSs. In China and Australia, they map powerlines.

**LM:** Please explain, in a simple way since I don't have degrees in either physics or electronics, how your technology differs from that of your competitors. Do you see your USPs in terms of price levels rather than technology or performance? You claim to be disruptive on price—please say more! I think that the high quality and reliability of the M8 have been publicized too.

**TY:** I can't say too much about how it's made. The differentiators are point density and lower price-point. Quanergy offers the best value in terms of $ per point, with only eight beams, compared to Velodyne's 16, but we are faster, with 432,000 points per second, compared to ~320K from Velodyne, so we are 40% higher. We do this through a very high firing rate of the laser, which facilitates a very high horizontal angular resolution of 0.03° compared to competitors' 0.1°. This is very helpful to engage customers. It's good for power lines, where it really makes a difference. Also, in order to have high data rates, we use optical fiber systems and inductance power transfer for reliability of construction and high efficiency. The current mapping product is not yet based on solid-state technology, but the second-generation product will be. Our security product is solid-state.

**LM:** So you use solid state technology, rather than micromotors? And you do something with the phase of the beam?
**TY:** Our first product like that is for entryway security—its productization has priority. It does not have a 360° FOV like the mapping product. 360° FOV is not necessary for flying, but is important for MMS. It's a spinning device, not a prism but a rotation mechanism inside

QORTEX

QORTEX™ is the perception software that Quanergy supplies with its lidar sensors. The QORTEX variants provide a flow management platform, resulting in a product family that currently comprises three solutions: QORTEX DTC (paired with M8), used for security and smart city; QORTEX People Counter (paired with S3-2) for smart space and smart city; QORTEX Access Control (paired with S3-2) for security and smart space.



Quanergy has been working on a joint development project with Zhejiang Geely Holding Group Co., Ltd, which is a Chinese automotive company commonly known as Geely. The project is located near Geely's headquarters in Hangzhou, Zhejiang province, China.

the unit, which is a mechanical part. The mapping industry has been enjoying the introduction of our lidar and not been so picky. In flying they have moving parts, so they live with it! Also, flight times are typically below 30 minutes, so the market does not yet demand solid state. There are different means to the end. We do indeed have a solid state solution, based on optical phased array technology. It's coming from interference patterns—think of throwing two rocks in the water and looking at the patterns. Think of thousands of rocks, and total control over where you throw them. You control the phases, so can control the outgoing beam and can steer it by controlling the phase. It's all electronic, with no moving parts. Radar is also based on the phased array but at a different wavelength from our 905 nm.

**LM:** Good price-point, high reliability, customer satisfaction. No-one will complain about that approach!

**TY:** We want to focus on the product speaking for itself and customers speaking for the product. We invited customer vendors to our booth at CES.

**LM:** Have you had any thoughts on going public?
**TY:** No thought of going public. We focus on execution. M&A is another possible question, they are all symptoms of success. You must stand on your own feet and become successful.

**LM:** There must come a point when you don't need VC any more. You can use revenue and profit.
**TY:** We are still in the growing phase, so we need funding. We are not profitable or saving money for dividends, so we need VC injection. Going public is one way to get funding, but in the Valley there are huge private companies. The board will decide what is best.

**LM:** Clearly, you have to offer low-level software or APIs so that your customers can enjoy your sensors, but with the QORTEX you seem to be offering quite extensive software. Is that right?
**TY:** We do offer an SDK with M8 so end-users can use output to build their own software. Customers are at different levels, e.g. Jeff Fagerman doesn't use our SDK but builds his own. Some other customers use our SDK to feed into their own systems. Other customers want object information rather than raw data, so they use our software.

**LM:** How did CES 2020 go? Do you enjoy trade shows? During the show, you announced the partnership with Geely—please tell us more about that?
**TY:** Yes, it was a good show. We have

been there for six years now, demonstrating a different aspect each year and this year we invited customers to co-exhibit. Remember our focus is not just automotive but wider. We set out to be in other markets. The Geely relationship is very exciting. The project is more on the smart city front. In Geely's HQ, there are intersections with M8s mounted. It's a pilot project. Currently smart city projects are government-driven, but Geely's is private and the pilot went very well. We collect intersection information, both pedestrian and vehicles, and send it to the vehicle to make things safer: infrastructure-car communication, which is also tied to 5G. We also had a project in Adelaide, Australia[3].

View of part of Quanergy's facility in Sunnyvale, California.

**LM:** What is your relationship with Jaguar? I ask that because they make nice cars and they're British, albeit with Indian ownership!
**TY:** We had a press release in 2017. We have similar partnerships with many car companies. You can't buy a Jaguar car with our lidar yet!

**LM:** Your big, exciting market is autonomous vehicles. It may be some time before these are universally permitted and commonplace, but is the ADAS market attractive to you in the meantime?
**TY:** ADAS and AV are two parallel tracks in the AV market. The whole thing is about reducing cost.

**LM:** I see two other competitors who could be interesting. Livox, which is related to the AV supplier DJI, seems to have some new technology. Intel, which has been active with its ADAS/AV Mobileye acquisition for some years, recently launched the RealSense L515 at under $500. Do you have any thoughts on these entrants?
**TY:** Intel has been active for a number of years, e.g. for the stereo camera. Again, it supports the notion of 3D. It has range limitations and is prone to lighting changes. It performs well in warehouses and indoors. Our take is, "The more players, the better". It's better, if you're confident in yourself, your competitiveness, to have more people scratching the surface together and then you discover more applications. We need to out-innovate ourselves and then we can stay in the leadership position. Livox's cheap model is $800. They are located in a manufacturing hub of China and they are part of DJI, so have a ready outlet. They have different versions of the product. You can't make a product that suits everything.

**LM:** Intel's MobilEye was an acquisition.
**TY:** Yes, in 2017, in addition to RealSense stereo cameras. They are focusing on the ADAS market. MobilEye began around 1999. After first 10 years, it's hard, you have to build the foundation. They are keeping a big base in Israel.

**LM:** What does the future hold for Quanergy, especially in the geospatial market?
**TY:** We are growing in many different markets, in accordance with our vision. We address markets in parallel with AVs, which is also in the R&D stage. We support AV customers as a supplier, but in other markets we are a big player: in security and IoT, we focus on products to stay in a leadership position. The second player climbs across your body. Multiple markets are an advantage. The geospatial

3 https://www.youtube.com/watch?v=i7FXIgBO9o0; https://www.computerworld.com/article/3471433/adelaide-pilots-smart-city-technology.html. The Quanergy components were M8s and Qortex DTC (detection, tracking and classification) software.

market is an emphasis this year. We have a successful M8 but we want to keep our leadership position. We had a meeting yesterday with our business team about updates. We don't want to stay in the same place—product cycles are fast and people catch up. We listen to the customers, value their inputs and do what we need to do to fill gaps.

**LM:** Dr. Yu, thank you very much indeed for your time and frank answers.

## A look round

Yu and Bhunnar took me on a quick factory tour. Quanergy had doubled its space, within the same building, in 2019. The heavily used facility, packed with cubes, benches, tools, electronic components and finished or partially finished lidar sensors, was not so different from scenes at Applanix and Cepton Technologies that *LIDAR Magazine* had witnessed during research for other articles. Quanergy used to have production in the Sunnyvale headquarters, but, as demand has increased, is outsourcing it, to companies that can ramp up very fast for mass production. They do pre-production and develop software in Sunnyvale. Bhullar showed the main components of the M8 and how they are assembled. Various sub-assemblies, such as the rotating mechanism, are tuned for maximum performance, e.g. alignment, range and smoothness. Getting the best range is vital in competition. Then there is balancing, integration and testing—calibration, burn-in, range test, accuracy test etc. Yu said they also use third-party test facilities for procedures they can't do in-house. "Our quality is the best in the world in the lidar industry at this time," said Bhullar. Yu agreed! "We're very proud of our industry awards and we're confident of our processes"[4]. The company's manufacturing processes are ISO 9001:2015 compliant. We looked at the solid-state lidar for people-counting. Yu was in her element, showing me the components and trying to explain to me how it all works. There are variants of the technology platform, so there are ways to be agile to meet future demands. Yu is involved in the design, but then comes the fabrication. The chip fabrication is done in Silicon Valley: this service is easy to find locally as three quarters of the world's expertise is within 20 miles. We walked through the garage area, where there were two AVs under development, donated by Mercedes, an endorsement of which Dr. Yu was clearly proud. They also collaborate with Toyota and other car companies. She showed me the water-resistant parts. Rather than IP67, they have IP69K, which is appropriate for fitting on garbage trucks that are power-washed every day. Yu also stressed every unit's two-year warranty.

Back in the conference room, we discussed how crowded the mapping market-space is, but I admitted it is still hard to judge the size of the UAV-lidar market. Quanergy knows the UAV-lidar integrators, but wants more market share. The company is agile, active and hungry. I was impressed with their keenness to understand the geospatial lidar market and the players.

## Endnote

I left Sunnyvale with much to ponder. Silicon Valley is different. The technological and intellectual excellence, energy and drive of the players are palpable and rub off on visitors. Quanergy and its competitors will continue their intense activity in the automotive and other markets. The geospatial world, therefore, will be a big beneficiary as performance and quality rise, prices fall, the integrators prosper and the end-users relish the ROI.

## Postcript

This interview took place on 15 January 2020. On the following day, Quanergy revealed that Dr. Eldada had stepped aside as CEO and would continue in a "consultant and evangelist role"[5]. Indeed, he had left the board of directors on 13 January, with Dr. Kevin Kennedy taking over as interim CEO. Dr. Kennedy had joined Quanergy's board in April 2019 and became chair in October. Clearly, Dr. Yu could not reveal this news to me, since the interview took place before the embargo date.

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4 Quanergy has won multiple awards including: Consumer Electronic Show's (CES) 2017 Best of Innovation Award in the vehicle intelligence category for its S3 solid-state lidar sensor; 2017 ASTORS Homeland Security Award for Best Perimeter Protection System; Best Consumer Product in Automotive and Telematics from Juniper Research in its annual Future Digital Awards for Technology and Innovation in 2018; 2018 Silicon Valley Chamber of Commerce's 2018 Murphy award for Outstanding Innovation in LiDAR Sensing Technology; and 2019 Best of Sunnyvale Award in the Manufacturers category.

5 https://www.bloomberg.com/news/articles/2020-01-16/quanergy-ceo-steps-down-after-driverless-tech-unicorn-stumbles. Interestingly, the title of this article includes the word "unicorn". Yu would not be drawn during our interview by my question whether Quanergy was a unicorn.

# Measuring Maria's Havoc in Puerto Rico

## Evaluating hurricane damage with multi-temporal lidar

### USGS and Florida lidar standards

The National Enhanced Elevation Assessment Report[1] (NEEA) of the U.S. Geological Survey (USGS) indicated that the greatest national return-on-investment would be experienced when lidar and terrain data met the USGS Quality-Level 2 (QL2) standards for the continental U.S. and Hawaii, and was recollected on an eight-year acquisition cycle. A similar study conducted in 2017 by the state of Florida, the Florida Statewide Lidar Assessment[2], built upon the USGS NEEA study and recommended the higher USGS Quality-Level 1 standard and a more frequent, three-year acquisition cycle. These higher standards for Florida arose, in part, because the higher quality and increased acquisition cycle are necessary to adequately represent the low-lying, frequently flooded coastal areas, and to assess how hurricanes alter the landscape. Both the USGS NEEA and the Florida Statewide Lidar Assessment point to the increased benefits of multi-temporal lidar data or, at minimum, repeated *ad hoc* surveys.

### 2017 hurricane devastation in Puerto Rico

The hurricane season in late summer/early fall of 2017 was devastating to Puerto Rico. In the early evening of September 6, 2017, the eye of Hurricane Irma passed just north of the island as a Category 5 Storm and left more than a million people without power. Then, only two weeks later, on September 20, 2017, Hurricane Maria made landfall just south of Yabucoa Harbor and passed through the island as a Category 4/5 Storm (**Figure 1**). As the worst storm to hit Puerto Rico in more than 80 years, Hurricane Maria's 155 mile-per-hour winds uprooted trees, downed powerlines and cell towers, ripped the roofs off houses, and left behind flooding and swollen rivers. The entire island was left without electrical power.

### Lidar data collection

Not necessarily in preparation for the 2017 hurricane season—but fortuitously—USGS, under the 3D Elevation Program (3DEP) that resulted from the NEEA study, contracted with Dewberry to map Puerto Rico to the QL2 lidar specification as specified in the National Geospatial Program Lidar Base Specification (LBS) 1.2[3] in 2016. The survey was conducted in two campaigns (**Figure 2**). The first campaign occurred from January 26, 2016 through May 15, 2016 and acquired 2316 square miles of topographic lidar data. The second campaign occurred from December 8, 2016 through March 16, 2017 and acquired 1779 square miles of topographic lidar data. The 2016 topographic lidar survey project, before Hurricanes Irma and Maria, covered approximately 3451 square miles of the commonwealth of Puerto Rico, which includes the outer islands of Culebra, Desecheo, Mona, Vieques, Muertos, Cabeza de Pero, and Cayo Icacos. Lidar data collection parameters are given in **Table 1**. Dewberry's intent had been to collect all 4094 square miles in one campaign, but after about 85% was collected in the 2016 campaign (3451 square miles), the weather turned and the decision was made to halt collection and resume in 2017. The data from the first campaign was processed as Delivery Block 1 (2316 square miles). The remainder of the project was flown in 2017 and then the second delivery block was processed (1779 square miles).

1 https://pubs.usgs.gov/fs/2012/3088/pdf/fs2012-3088.pdf
2 http://publicfiles.dep.state.fl.us/FGS/GIS/LiDAR_Assessment/FL_LiDAR_Assessment_2017.pdf
3 https://pubs.usgs.gov/tm/11b4/Version1.2/tm11-B4.pdf

BY AL KARLIN, AMAR NAYEGANDHI AND RAYMOND MILLER

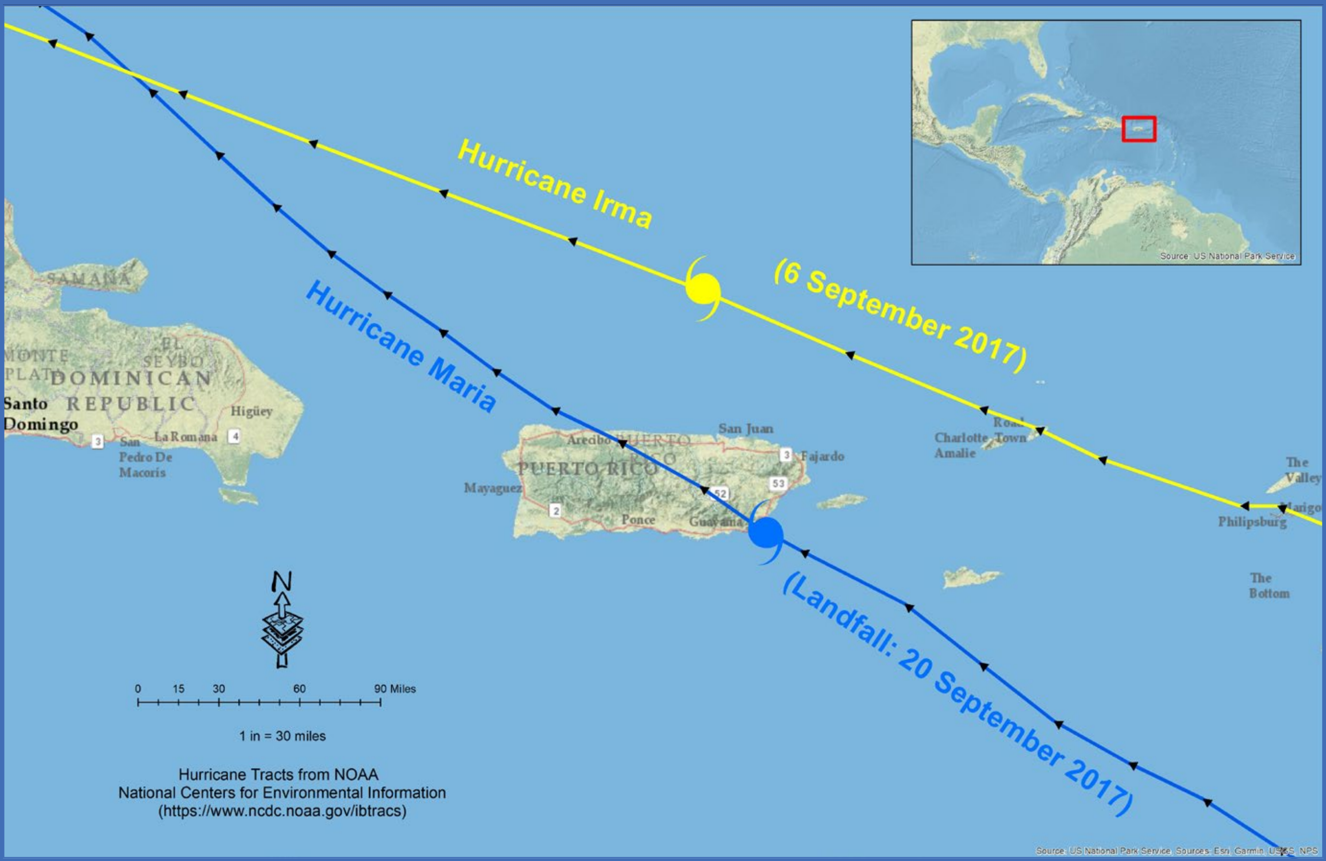



**Figure 1:** Puerto Rico showing the tracts of Hurricane Irma and Hurricane Maria in September 2017

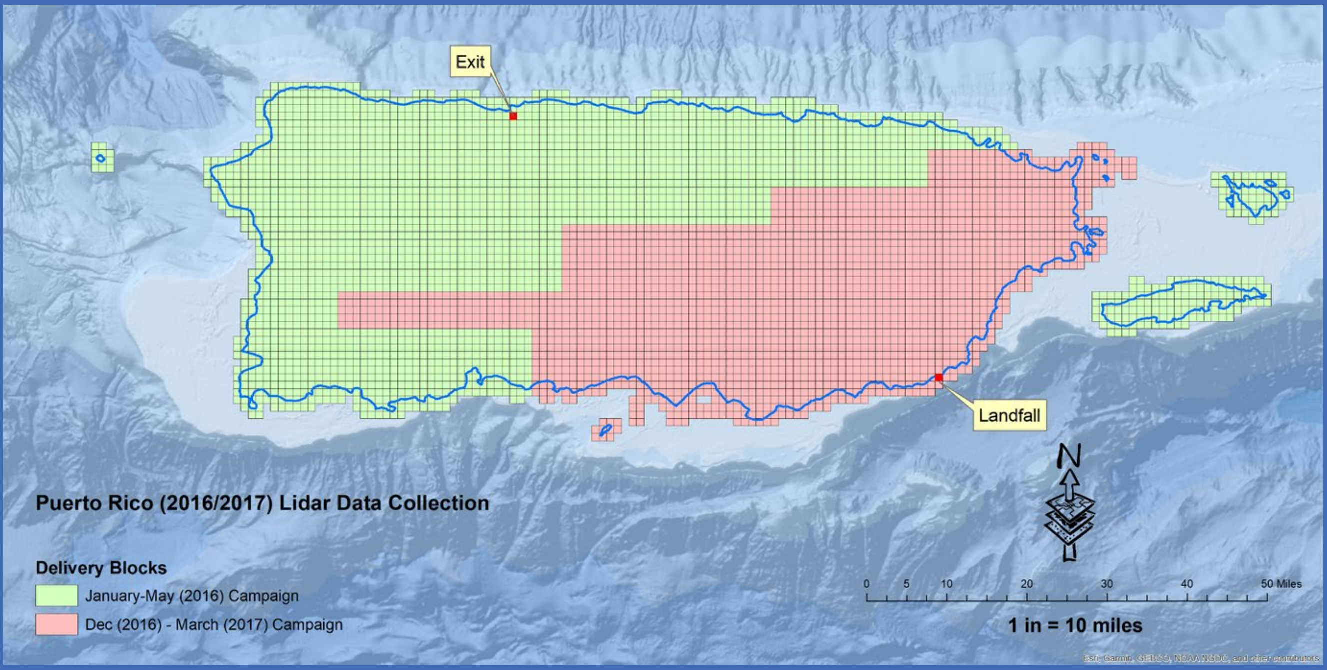



**Figure 2:** Dewberry topographic lidar data collection missions 2016/2017. Red tiles show areas where Maria made landfall (southern side of island; Figure 3) and exit (northwestern side of island, Figures 4 and 5).

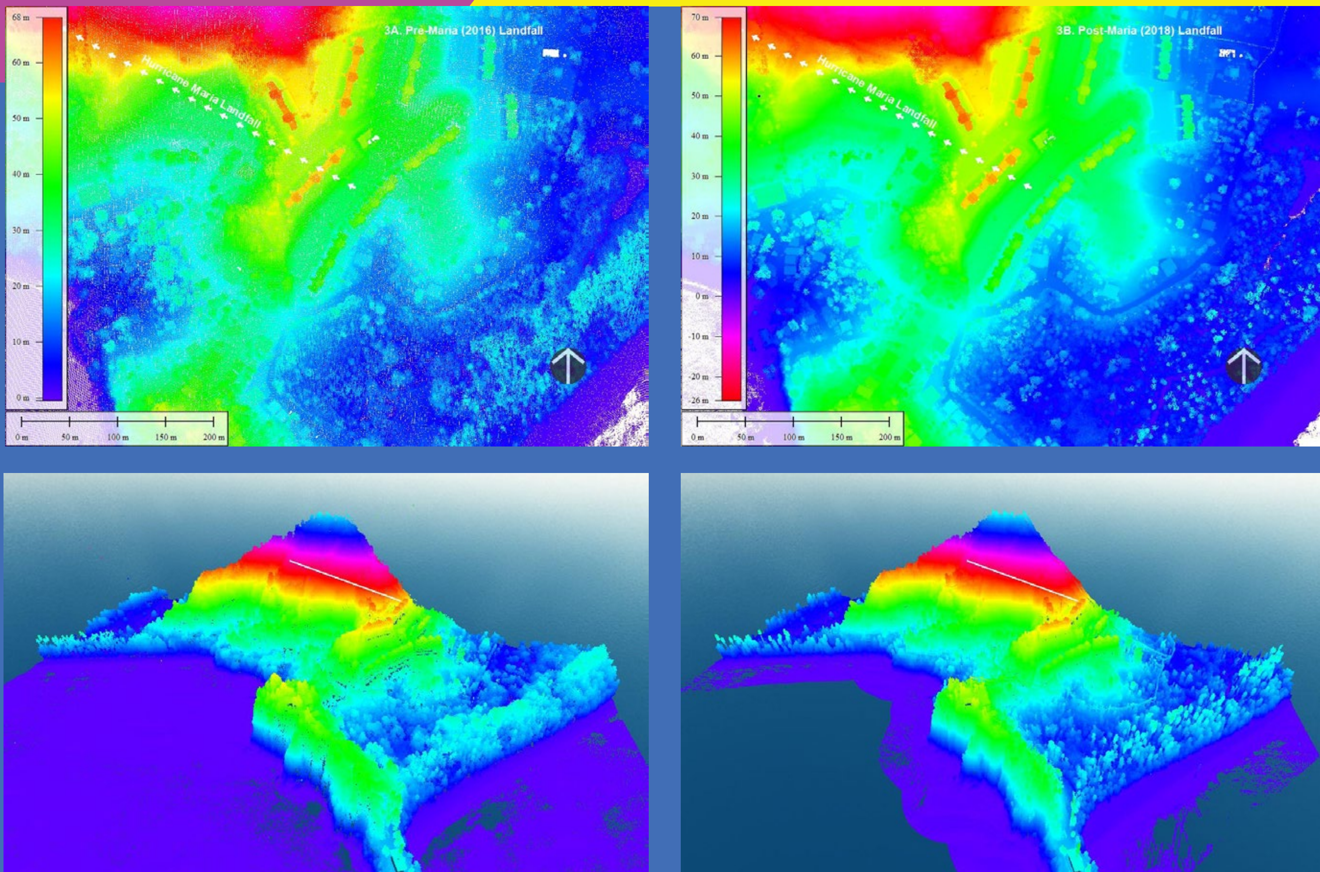



**Figure 3:** Full lidar point cloud (upper views nadir; lower views oblique), before (left; notice the dense vegetation in the foreground) and after (right; dense vegetation decimated). Hurricane Maria made landfall at Yabucoa Harbor, Puerto Rico. The white arrows on the nadir views show the approximate location of landfall path; the white line on the oblique views shows the same path.

Following the 2017 hurricane season, USGS tasked Dewberry to perform a spring, leaf-off, 2018 lidar topographic survey of Puerto Rico, conforming to the same geographic footprint as the 2016 survey, but updated to the USGS QL1 standards as in the USGS National Geospatial Program Lidar Base Specification (LBS) v1.3[4] in support of disaster recovery efforts resulting from the impacts of Hurricane Maria. While many of the differences between LBS 1.2 and LBS 1.3 address ancillary and/or deliverable products—accuracy testing, and metadata—the Geoid 12a to Geoid12b update is of significance. Similarly, the upgrade in data pulse density from QL2 (2016) to QL1 (2018) was designed to provide greater ground resolution under debris and heavy canopy. Lidar data collection parameters for the 2018 topographic survey are shown in **Table 2**.

| | **Parameter** | |
|---|---|---|
| **Item** | **Jan 2016—May 2016 campaign** | **Dec 2016—Mar 2017 campaign** |
| **Sensor** | Riegl LMS-Q680i | Riegl LMS-Q780 |
| **Altitude** *(m AGL)* | 1100 | 900 |
| **Flight speed** *(approx. knots)* | 100 | 120 |
| **Nominal swath width on the ground** *(m)* | 1270 | 1039 |
| **Scanner pulse rate** *(kHz)* | 200 | 200 |
| **Scan frequency** *(Hz)* | 75 | 82 |
| **Nominal pulse spacing** *(single swath, m)* | 0.70 | 0.65 |
| **Nominal pulse density** *(single swath, ppsm)* | 2.1 | 2.5 |
| **Aggregate nominal pulse spacing** *(m)* | 0.50 | 0.46 |
| **Aggregate nominal pulse density** *(ppsm)* | 4.0 | 4.8 |

**Table 1:** Lidar data collection parameters for 2016 (pre-hurricane) Puerto Rico topographic survey

4 https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf

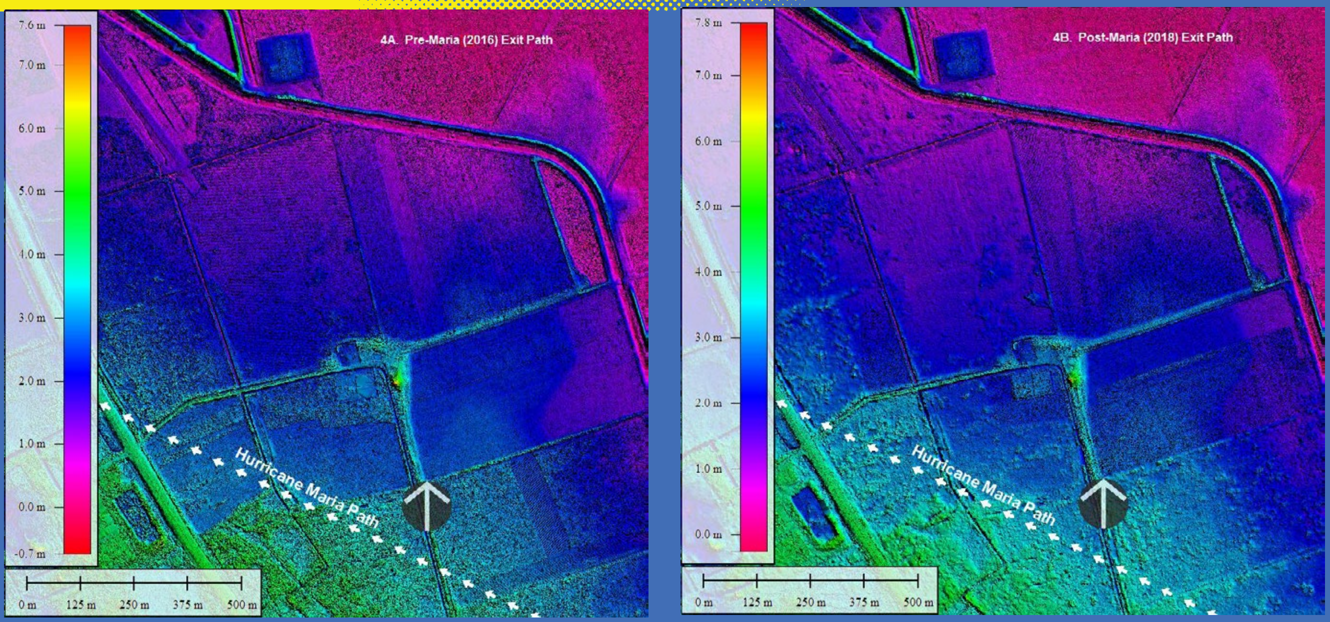



**Figure 4:** Full lidar point cloud, before (left) and after (right) Hurricane Maria exited Puerto Rico. The white arrows below the north points show the approximate direction of the exit path.

| Item | Parameter | |
|---|---|---|
| **Sensor** | Riegl VQ-1560i | Riegl LMS-Q780 |
| **Altitude** *(m AGL)* | 1000 | 800 |
| **Flight speed** *(approx. knots)* | 150 | 100 |
| **Nominal swath width on the ground** *(m)* | 1064 | 924 |
| **Scanner pulse rate** *(kHz)* | 700 x 2 | 200 |
| **Scan frequency** *(Hz)* | 175 x 2 | 122 |
| **Nominal pulse spacing** *(single swath, m)* | 0.22 | 0.42 |
| **Nominal pulse density** *(single swath, ppsm)* | 10.3 | 5.7 |
| **Aggregate nominal pulse spacing** *(m)* | 0.22 | 0.21 |
| **Aggregate nominal pulse density** *(ppsm)* | 10.3 | 11.4 |

**Table 2:** Lidar data collection parameters for 2018 (post-hurricane) Puerto Rico topographic survey

## Lidar point clouds before and after Hurricane Maria

Hurricane Maria made landfall on the southern side of the island of Puerto Rico (**Figure 1**) as a Category 5 storm. The immediate area, just south of Yabucoa Harbor, is populated and the coastline is heavily vegetated. Hurricane Maria modified the beach and removed some of the vegetation along it as seen in **Figure 3**.

Similarly, as Hurricane Maria exited Puerto Rico along the northern coast of the island, as a Category 4 Hurricane, it leveled the landscape. The tree loss is clearly visible in the 2016 and 2018 lidar point cloud images in **Figure 4**.

While the hurricane's effect on the vegetation was most obvious as the destruction of the tree canopy, the ground-level terrain elevations were also affected. **Figure 5** shows the same geographic area as **Figure 4**, filtered to a ground-only point cloud. In **Figure 5**, mounding (red area) is evident along the path of the hurricane. The mounding is most pronounced along the western edge of the image and is clearer in the oblique views. Moreover, leveling of the surface accompanies the mounding as is evident northward of the large mound.

Using this exit area as an example, we generated a difference DEM (**Figure 6**) to compare the pre-Maria ground surface to the post-Maria ground surface. Areas in red represent mounds, green areas experienced little elevation change, and areas in blue were scoured out. As expected, the elevation changes were normally distributed so there was no net gain or loss, but materials were relocated, forming new swales and depressions.

## Project challenges

While the advantages of multi-temporal lidar missions for disaster relief and recovery are obvious from the above analysis, there were also significant challenges to this project:

- **Terrain:** Even though the island of Puerto Rico is relatively small—at

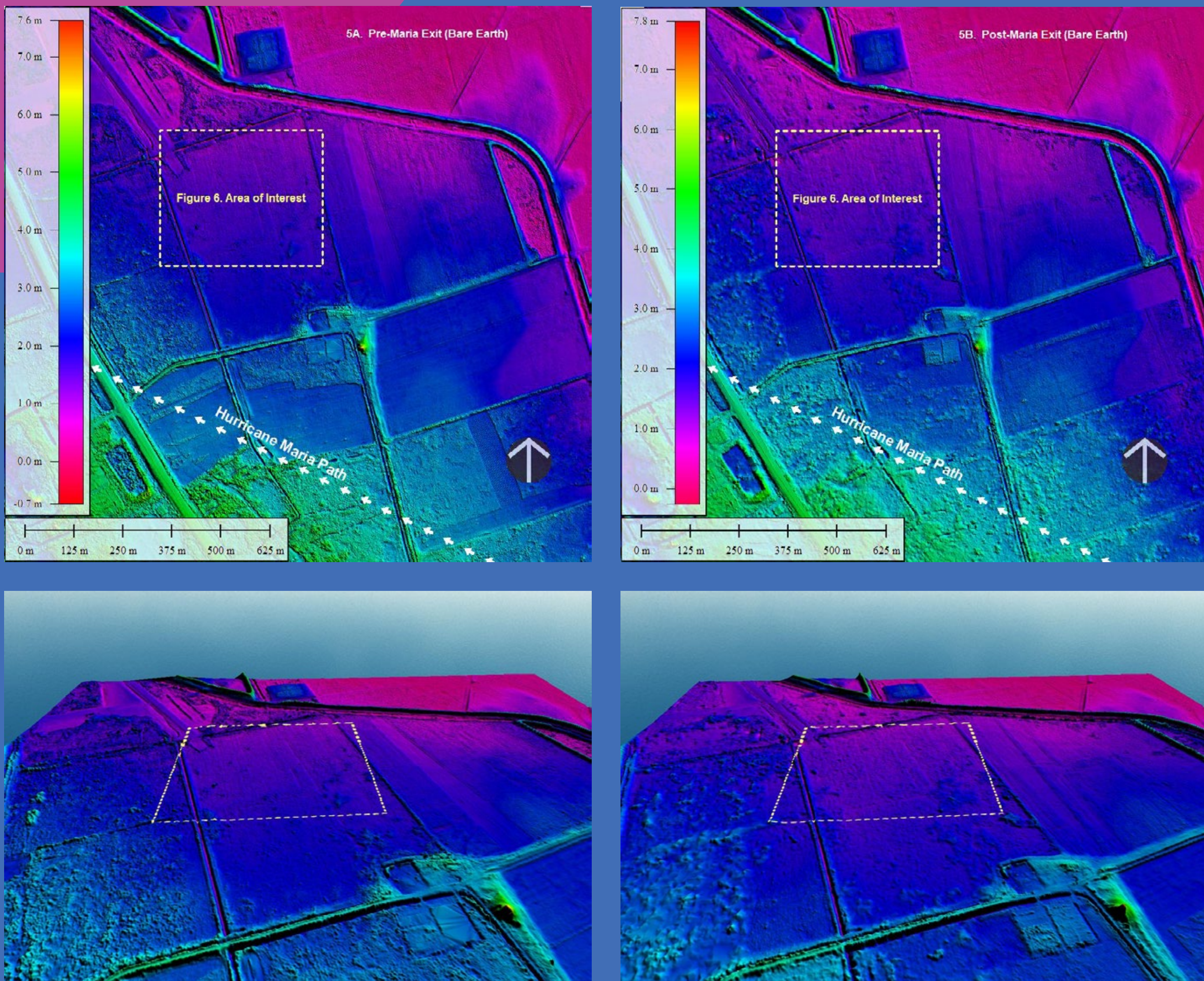



**Figure 5:** Classified (Ground/Class 2) lidar point cloud, before (left) and after (right) Hurricane Maria exited Puerto Rico. The graphics in the top row are verticals and those in the bottom, obliques. The white arrows below the north points in the vertical views show the approximate direction of the exit path. The rectangular area indicated by the dashed white lines is the area of interest shown in Figure 6.

3400 square miles, it is the smallest island in the Greater Antilles—it is mostly mountainous. The main mountain range, La Cordillera Central (the Central Range), reaches heights of 4390 feet above mean sea level (AMSL). Two major peaks, Cerro de Punta and El Yunque (in the El Yunque National Forest) reach almost 4400 feet and 3500 feet AMSL, respectively. These terrain features present significant challenges and dangers to small aircraft.

- **Environment:** Related to the terrain, the environment of Puerto Rico is classified as a tropical rainforest. Temperatures are warm to hot throughout the entire year and, together with prevailing winds, produce thermals near the mountains, which is challenging and dangerous to small aircraft.
- **Climate/Weather:** There is no dry season in Puerto Rico. The average annual rainfall is in the range of 56 to 60 inches, averaging about five inches per month dispersed over about 18 rainy days. With coastal water temperatures about 20 degrees lower than land temperatures and the terrain, clouds form regularly in the late morning, followed by afternoon rains and humid nights. Constant rain, clouds, and nighttime humidity are all challenging conditions for lidar data acquisition, particularly in Puerto Rico's mountainous rain forests.
- **Restricted airspace:** U.S. military installations in Puerto Rico are part

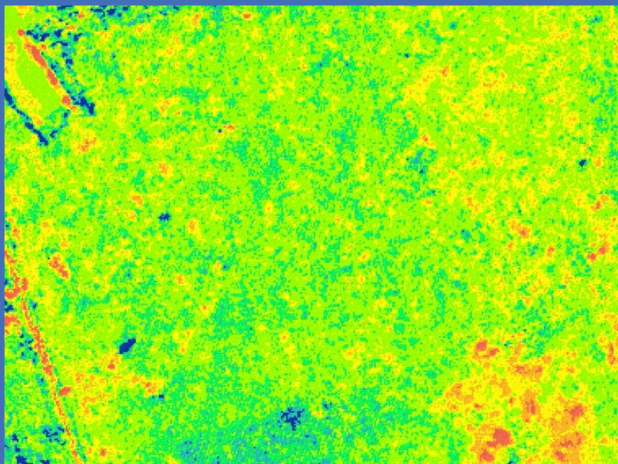
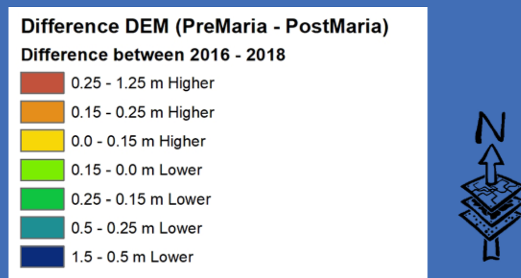


Figure 6: Difference DEM (pre-Maria and post-Maria) showing areas of ground accumulation (in red) and ground loss (in blue). The location of this area of interest is shown in Figure 5.




of the U.S. Northern Command. Bases with restricted airspace include Roosevelt Roads Naval Station, Ramey Air Force Base, U.S. Naval Radio Station, Fort Allan Naval Radio Station, and several U.S. Coast Guard bases and Puerto Rico Air National Guard bases. Puerto Rico also contains several conservation areas, including El Yunque National Forest and the National Wildlife Refuges in Culebra and Vieques, where close coordination with officials was required to prevent disturbances to wildlife. Negotiating the weather in conjunction with air space restrictions was extremely challenging.

## Conclusions

The fortuitous opportunity to collect topographic lidar data before and after an environmental event such as Hurricane Maria afforded the opportunity to evaluate the impact of a Class 5 hurricane. As lidar was collected at the points of both landfall and exit, it was possible to determine the effect of the hurricane traveling over Puerto Rico.

The most obvious impact of the hurricane was easily identified in the vegetation by examination of the lidar point cloud. At the point of landfall, the toppling of trees was evident even after the two-year temporal difference in the lidar missions. Similarly, the vegetation difference was obvious between the collections, even in areas as the hurricane exited land.

Most striking were the ground surface-level changes. As is documented above, in the area near the hurricane's exit path, the hurricane-force winds and rain resulted in surface-level alterations. Ground was mounded, in some places by up to more than one meter, along the hurricane's path, and comparable depressions, up to a meter deep, representing the soil that was transported, were created. The two-year separation between lidar surveys indicates that these land/surface alterations, which may alter long established drainage patterns, are persistent in the terrain long after the hurricane passes.


## Acknowledgements

We thank USGS, the National Oceanic and Atmospheric Administration (NOAA), the Commonwealth of Puerto, and the National Park Service, which funded these projects. We also thank Tim Saultz and Gail Dunn of USGS for their coordination efforts and overall support.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**Amar Nayegandhi, CP, CMS, GISP** is a vice president and director of remote sensing at Dewberry. He oversees the geospatial and technology services group for Dewberry's contracts with federal, state, and commercial clients. With more than 20 years of experience, he is a recognized expert in topographic and bathymetric lidar data acquisition and processing. Amar has a bachelor's degree in electrical engineering from the University of Mumbai and a master's degree in computer science from the University of South Florida. He is a former director of the ASPRS Lidar Division, an ASPRS Certified Photogrammetrist and Certified Mapping Scientist—Remote Sensing, and a GIS Certification Institute Professional.

**Raymond Miller, Jr., CP, CMS, GISP** is a project manager in Dewberry's Tampa, Florida, office. He has extensive experience in GIS, remote sensing, and relational database management. He has developed geospatial solutions for water resources, floodplain mapping, and hazard mitigation projects for clients that include the SWFWMD, NOAA and the Florida Division of Emergency Management. His experience includes lidar data production and analysis, digital terrain modeling, watershed evaluation and management planning, floodplain mapping, and geodatabase management. He is a Certified HAZUS Professional, ASPRS Certified Mapping Scientist—Remote Sensing, and a GIS Certification Institute Professional.

# Lidar Initiatives at the National Center of Cartography Romania

## 2D–3D data fusion research in the VOLTA project

ADRIAN PÂRVU, NORBERT PFEIFER AND MARGARITA DOGARU

### National Center of Cartography Romania

The National Center of Cartography Romania (CNC) offers specialized technical support to develop and update geodetic and cartographic databases at the national level to fulfill the tasks of the National Agency of Cadaster and Land Registration (ANCPI) and of the territorial offices of cadaster. CNC evolved in 2011 from the Institute of Geodesy, Photogrammetry, Cartography and Land Administration, founded in 1958, and is a governmental institution.

The responsibilities of CNC's Cartography and Photogrammetry Department (SCF) include:

- permanently provide cartographic data to ensure the geospatial data infrastructure within the INSPIRE Directive
- develop, maintain and update the digital terrain model at the national level, based on the data provided by CNC and third parties
- exploit photographic images using photogrammetric systems
- develop photogrammetric products derived from national cartographic databases
- perform quality control (QC) of projects and works carried out in the field of photogrammetry and cartography.

SCF works with orthophotomaps and lidar point clouds. In these areas, CNC is the national authority that can provide QC for third parties' products. ANCPI has an ongoing project that involves acquiring images and point clouds, to produce orthophotomaps, DSM and DTM. The project area covers six counties of Romania (**Figure 1**). SCF's task for this project, called LAKI II (Land Administration Knowledge Improvement), is QC. As a parallel activity, SCF is carrying out research studies using ALS data.

### VOLTA project

Another important project for CNC is the European research project 734687 — VOLTA — H2020-MSCA-RISE-2016 (innoVation in geOspatiaL and 3D daTA; **Figure 2**). VOLTA[1] is an EU Marie Slodowska-Curie RISE (Research and Innovation Staff Exchange) action designed to realize research & innovation (R&I) among intersectoral partners by exchange of knowledge, methods, and workflows in the geospatial field. CNC's VOLTA project plans to design and

1 http://volta.fbk.eu

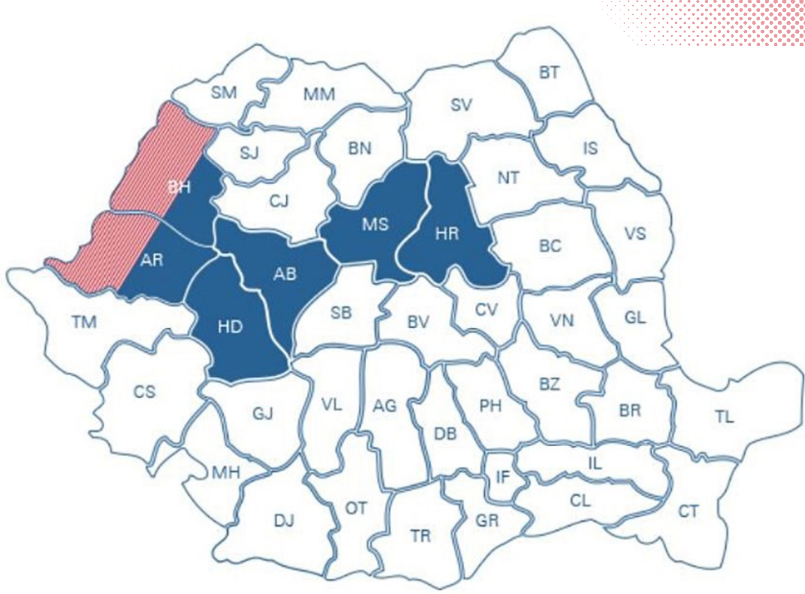



**Figure 1:** Area of LAKI II project. The areas in pink had completed the QC when this map was created.

validate innovative processing and handling methodologies for 3D geospatial data to support practical applications of photogrammetric mapping approaches. To accomplish its objectives, the main R&I activities of VOLTA are divided into four interlinked work packages (WP) with two transversal ones responsible for knowledge transfer and training as well as dissemination of the project results. The research activities and knowledge transfer are performed with a series of secondments between partners. The consortium is composed of 13 partners from academic and research institutions, industrial partners and national mapping agencies:

- Fondazione Bruno Kessler (FBK)—Italy
- Technische Universität Wien (TUW)—Austria
- Leibniz Universität Hannover (LUH)—Germany
- Technische Universiteit Delft (TUD)—Netherlands
- Uniwersytet Warszawski (UW)—Poland
- Geodetski Zavod Celje (GZC)—Slovenia
- Vermessung AVT—Austria
- Vexcel Imaging—Austria
- GeoImaging (GEO)—Cyprus
- Institut National de l'Information Geographique et Forestiere (IGN)—France
- Ordnance Survey (OS)—United Kingdom
- Institut Cartogràfic i Geològic de Catalunya (ICGC)—Spain
- CNC—Romania.

The VOLTA-CNC team is involved in 16 secondments and other events, such as workshops, summer schools and conferences, until 2021. We are proud to work during secondments with such academic partners as TUW, LUH, TUD, UW, IGN, and research institutions such as FBK.

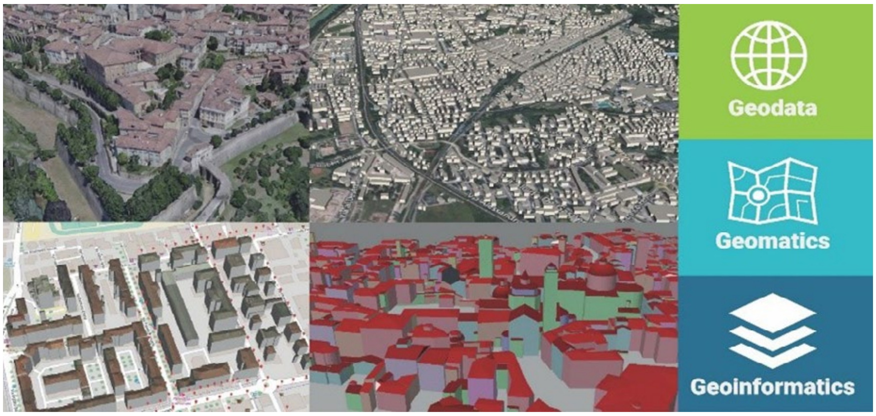



**Figure 2:** Topics in VOLTA project

VOLTA
innoVation in geOspatiaL and 3D daTA

Figure 3: Danube River in Vienna
*(source: https://hiveminer.com)*

## 2D-3D data fusion

In this article we show the research activity and results of the secondment from 2018, at the TUW. The secondment was part of WP: Data and sensor integration, with the task 2D–3D data fusion. The supervisor at the hosting institution was Prof. Dr. Norbert Pfeifer, head of the Research Group Photogrammetry in the Department of Geodesy and Geoinformation. Our goal was to give the third dimension to all the water surfaces in the city of Vienna.

The biggest water polygons were part of the Danube River (**Figure 3**). The input data consisted of a classified ALS dataset with a density of 15 pts/$m^2$ and a 2D dataset of water surfaces. We worked on 2D-3D data fusion using ALS point clouds in OPALS (Orientation and Processing of Airborne Laser Scanning data, a dedicated point-cloud software suite developed by the Research Group Photogrammetry[2]). It is a modular program system consisting of small components (modules) grouped together thematically in packages. The aim of OPALS is to provide a complete chain for processing ALS data (waveform decomposition, quality control, georeferencing, structure-line extraction, point-cloud classification, DTM generation) for several fields of application, such as forestry, hydrography, city modeling, and power lines.

The input data consisted of 120 million classified ALS points (X,Y,Z, class) and 28,000 water polygons (X,Y) (**Figure 4**). As the water polygons originated from a cartographic product, water bodies were broken into individual polygons at bridges and weirs. Some of the water bodies were so small that they were not covered by lidar points. Thus, a subset of bigger water bodies was used in the research.

2 www.geo.tuwien.ac.at/opals

Figure 4: Input data: 2D water polygons (left) and ALS point cloud (right)

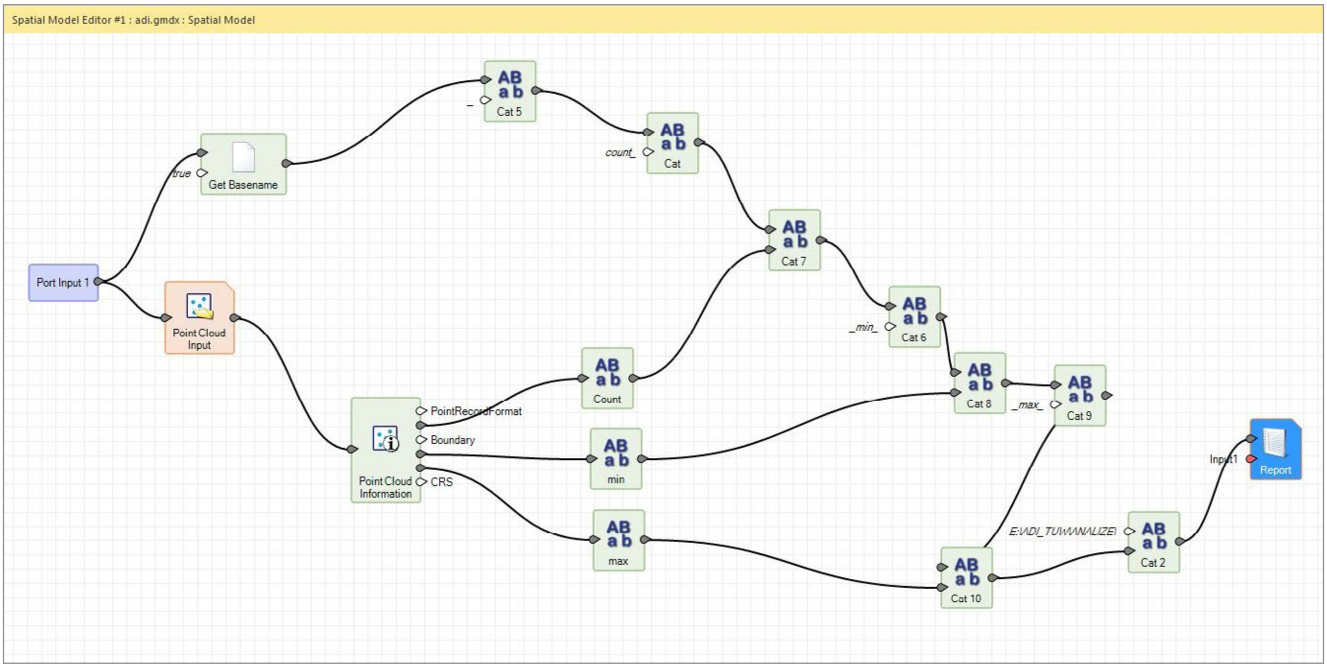



**Figure 5:** Spatial Model

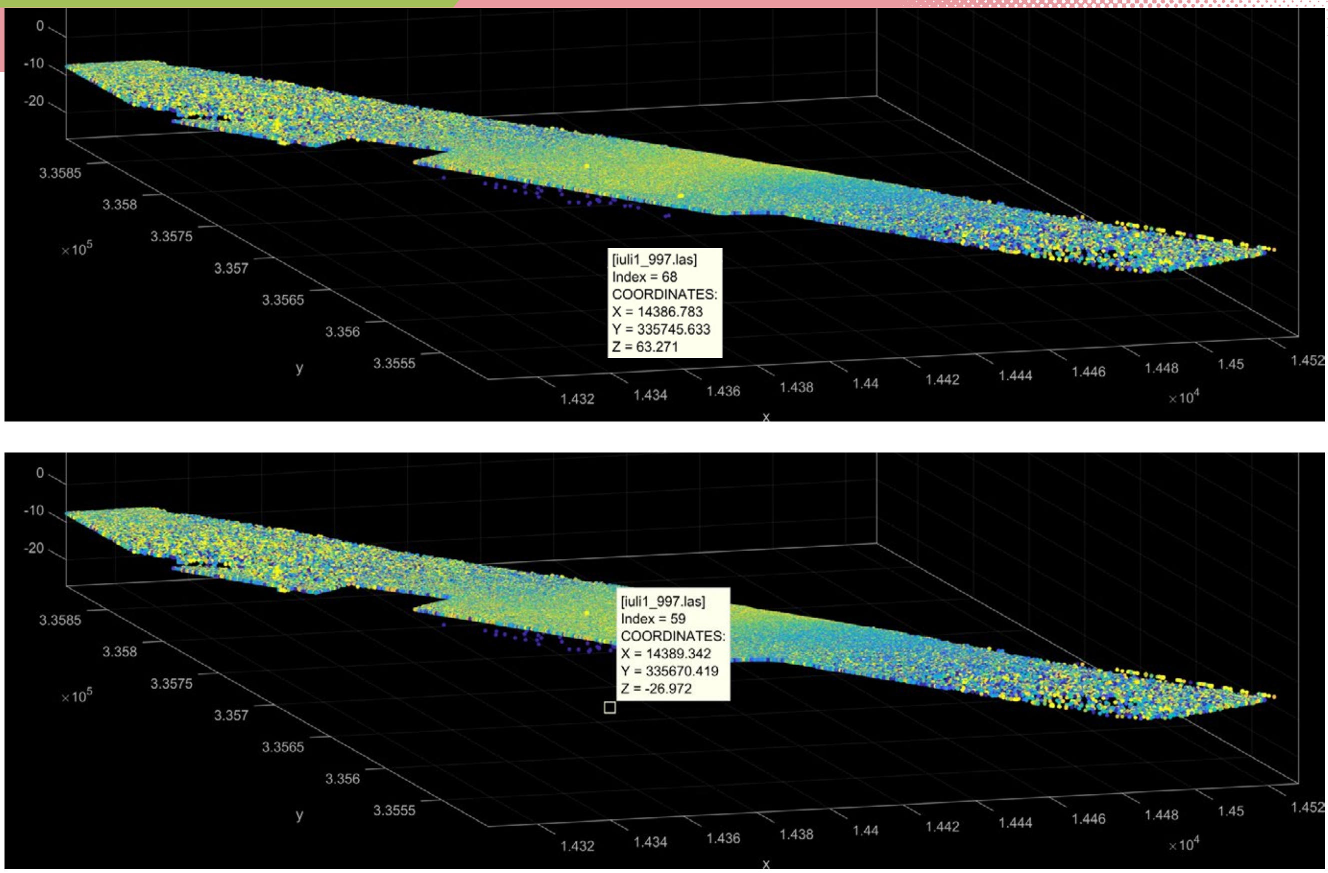
To perform the 2D-3D data fusion, we considered the water surface to be flat. We also took into account that the Danube River flows through Vienna, entering from the north-northwest and exiting southeastwards. So, we went further and treated the water surface as a slightly inclined plane. With respect to geometry, the best approach is the use of robust planes.

The first step, in our workflow, was data analysis and filtering. Dataset analysis and statistics were done using QGIS and ArcGIS for the 2D (.shp) dataset, and CloudCompare and ERDAS IMAGINE for the 3D (.las) dataset. Furthermore, data filtering and subsetting, for point clouds using water polygons as AOIs, were performed using a Spatial Model in ERDAS IMAGINE (**Figure 5**), resulting in 964 files. This was followed by batch processing for file attribute extraction.

Next we made a case study of errors greater than 20 m. This showed that: gross errors could occur as isolated points but for some water bodies multiple outliers occurred; outliers can be high above or far below the water surface, or both; outliers occurred over both large and small water bodies; and it was assumed that the errors could be either classification errors or incorrect range measurements. So, we had 23 water bodies with outliers for the Z value.

As a next step, we did a robust plane estimation, using the module ZonalFit (OPALS) for the 3D dataset, for each AOI described by the 2D dataset. The module fits geometry models to a set of data points for multiple regions of interest. Laser scanning results in point clouds describing surfaces rather than single spots of interest. In certain regions, the surface geometry is known *a priori*. This applies to horizontal areas, tilted planes, or simple curved surfaces. The aim of the module is to compute the best fitting geometric model by least squares adjustment for each region, to calculate the deviations (residuals) for the individual data points and to return both the parameters of the geometries and the statistics of the deviations, such as mean, median, standard deviation, histograms, etc. Robust plane estimation is used to deactivate outliers. For each successful zonal fit, the residuals are computed for all contributing data points and a histogram of the deviations is derived together with standard statistical parameters.

The processing for this step was time-consuming, because of the large number of points, so we used the filter *Generic [random(uniform_int,1,N) == N]*. This randomly selected every N-th point for computing the histogram.



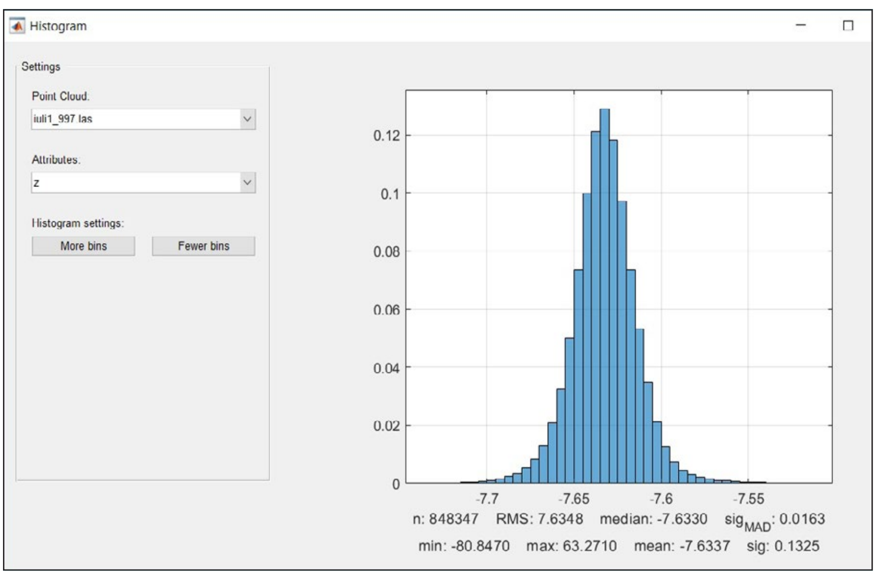




**Figure 6:** Data analyses for outlier detection (OPALS view): outlier Z = 63.271 m, far above water surface (top); outlier Z = -26.972 m, far below water surface (center); histogram of Z values, $Z_{min}$ = -80.847 m, $Z_{max}$ = 63.271 m (bottom)

## Final results

Using the geometric parameters obtained (A, B, C, D, dX, dY, dZ, which are the plane parameters and a reference point) in the previous steps, we computed the third dimension for the polygon vertices, using a Python script (**Figure 7**).

It was visually verified that the water polygons were assigned correct elevations, by comparison to lidar points within the polygons and in the surrounding areas. It was necessary to consider outliers, which are points not lying on the water surface. As discussed, these outliers originated in different steps of the preceding workflow.

To conclude, it can be said that an automatic workflow for 2D-3D-fusion was successfully developed using

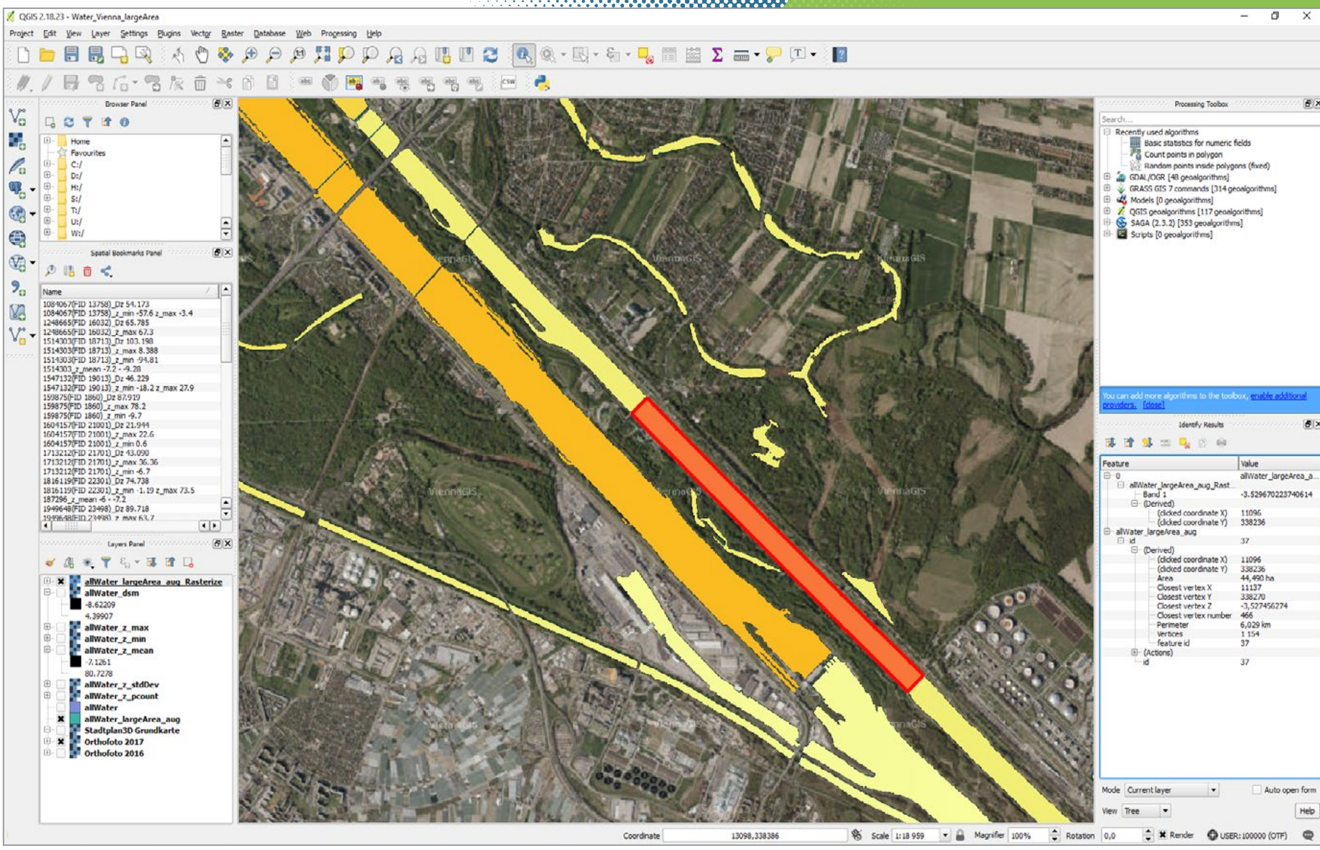



Figure 7: Output data. The background shows the orthophotomap and the water bodies are colored by their heights. One water polygon is selected and its properties are shown.

OPALS and Python scripts. Earlier in the workflow, a rigorous data analysis was necessary, studying a number of particular cases. This step was performed using ERDAS IMAGINE software. The robust plane estimation using module ZonalFit (OPALS) was a suitable choice for computing the third dimension for water bodies, but also for the elimination of outliers.


## Acknowledgments

The secondment of Adrian Pârvu was supported by the VOLTA project. The lidar point cloud of Vienna was provided for research purposes by the City of Vienna.


**Adrian Pârvu** is a geodetic engineer. He graduated from the Technical University of Civil Engineering Bucharest, Faculty of Geodesy in 2008 and has worked at CNC SCF since 2015. He is a member of the Romanian Society of Photogrammetry and Remote Sensing (SRFT). He is currently involved in the following activities: quality control of photogrammetric and remote sensing projects; study of the use of photogrammetric data in support of the National Program of Cadastre and Land Registration; workflow automation for building extraction from digital images—support for CENSUS 2021; MSCA-RISE VOLTA project.

**Norbert Pfeifer** completed his studies of surveying engineering at TUW in 1997 and obtained his Ph.D. in 2002 on modelling of fully 3D terrain surfaces. He worked as post-doc at TUD in the Photogrammetry and Remote Sensing section and later in the Department of Geography at the University of Innsbruck. Since 2006 he has been a full professor of photogrammetry at TUW. His research group specializes in laser scanning and photogrammetry for modelling of topography and vegetation.

**Margarita Dogaru** has been a geodetic engineer since 1983.She gained surveying experience on a construction site until 1986 and moved in 1987 to photogrammetry at the Institute of Geodesy, Photogrammetry, Cartography and Land Administration, Bucharest, working in analog and analytical photogrammetry until 1997 and then in digital photogrammetry. She has been head of the Photogrammetry and Remote Sensing Department since 1997 and, after reorganization of the Institute in 2011 into CNC, as head of SCF. She is president of the SRFT's Technical Commission II—Photogrammetry. She is coordinator of the CNC team in the VOLTA project.

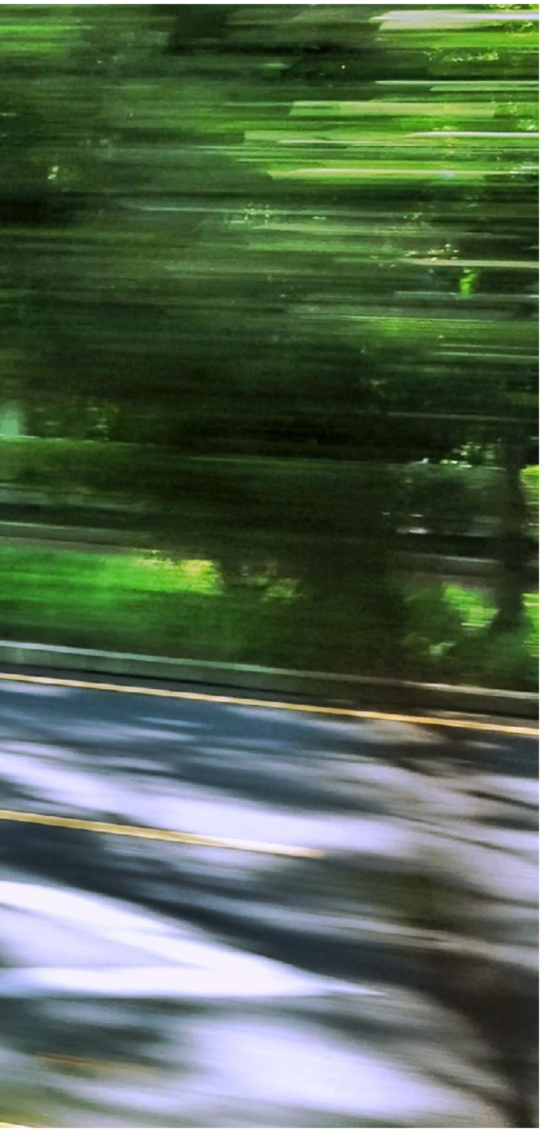
Self-driving vehicle with DeepRoute's technology

# AV Lidar Needs Software Too

## DeepRoute spearheads global AV industry with innovative technologies

BY DR. A. STEWART **WALKER**

DeepRoute.ai Ltd., which is based in Shenzen, China, with facilities in Beijing and Fremont, California, takes us further into an area that has become key for this magazine - the hardware and software necessary for lidar-equipped autonomous vehicles (AVs) to operate. We were offered a remote Q&A with a DeepRoute executive to provide a perspective on the company and its cutting-edge product,



DeepRoute-Sense, the company's level 4 full-stack self-driving system, which was first introduced in October 2019 and has subsequently been further refined.

DeepRoute offers unique software and hardware solutions for self-driving vehicles. The company works with top automotive OEMs, tier 1 suppliers, and mobility and logistic companies to achieve the commercialization of self-driving vehicles. The level 4 full-stack self-driving system was a CES Innovation Awards 2020 honoree for its unique combination of software and sensing solutions, offering a new driving experience to consumers.

The system is a combination of hardware and software, which leads *LIDAR Magazine* more towards the software side than our earlier pieces on automotive lidar.

Nianqiu Liu, vice president, DeepRoute.ai Ltd.

Guangchang Guo, chairman and co-founder of Fosun International Ltd., after a test ride in a vehicle equipped with DeepRoute technology. Fosun RZ Capital, the venture capital arm of Fosun International, led a pre-series A round for DeepRoute. This was announced in September 2019 and the amount raised was $50m.

We were pleased to be able to conduct the following Q&A with DeepRoute vice president, Nianqiu Liu (NL; first name pronounced "Nee-an-chi-oo").

**LM:** *LIDAR Magazine* has worked on articles with automotive lidar suppliers such as Cepton Technologies, Intel, Quanergy Systems and Velodyne LiDAR. The magazine originates in the geospatial world, which has benefited enormously because lidar sensors developed from the deep R&D pockets of the automotive world have been successful and economical when integrated on to UAVs or vehicle-based mobile mapping systems. We don't know so much, however, about DeepRoute, though we understand it was founded as recently as 2019. Please tell us something about the company: when it was founded; its leadership team; its locations and the reason for them; and its funding. We do understand that privately held companies such as DeepRoute have to be discreet about financial data, but even if you can say little about that, perhaps you can tell us how many employees are a part of the DeepRoute team?

**NL:** Founded in February 2019, DeepRoute has experienced significant

Front and side views of the DeepRoute-Sense vehicle roof box, only 31 cm tall

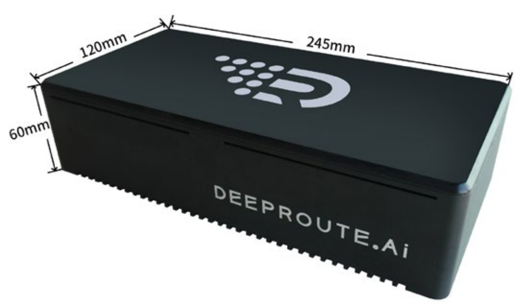
growth over the past year and a half and we have over 200 employees as of October 2020 across our three offices. The company has research and development centers in Shenzhen and Beijing. In addition to our R&D centers, we are testing self-driving vehicles in California. DeepRoute raised $50 million in our latest funding round in October 2019 to support production and operations . The financing round was led by Fosun RZ Capital, the Beijing-based venture capital arm of the Chinese conglomerate Fosun International[1] [Guangchang Guo DeepRoute.jpg]. Our proven technology and business model has garnered strong investor interest and has created a healthy pipeline of funds.

**LM:** DeepRoute is headquartered in Shenzhen, China, but has operations in Beijing and Fremont, California. How do you divide up activities between these centers?
**NL:** DeepRoute's global team works cross-functionally tackling projects in their location, driving innovation in each market. We have dedicated teams of engineers, developers and technicians in China and the U.S. office focuses on testing and business development.

**LM:** Does DeepRoute supply products, services or both?
**NL:** Both products and services. DeepRoute is a one-stop shop for automotive OEMs, tier 1 suppliers and mobility and logistic companies. With the products and services we provide, our customers can start testing self-driving technology on their vehicles right away. DeepRoute has developed several products, including:

- **DeepRoute-Sense:** a slim vehicle roof box equipped with eight vehicle-cameras, three lidars, a global navigation satellite system (GNSS), and other sensors, along with their corresponding telecommunication and data synchronization controllers.
- **DeepRoute-Tite** is the brain of the self-driving system. It processes the data collected by DeepRoute-Sense and transforms the data into driving instructions for vehicles.

  DeepRoute-Tite is extremely efficient and consumes significantly less power, only about 1/9 of the traditional solutions, mainly because we've developed a powerful duo of the inference engine and deep learning model, which minimizes the amount of computation required to output usable data.
- **DeepRoute-Syntric:** a data-synchronization device that can accurately detect surrounding objects in real-time to deliver a safe, smooth driving experience. DeepRoute-Syntric can also monitor the status of hardware, including sensors, and command the vehicle to stop when




DeepRoute-Tite

1 https://www.prnewswire.com/news-releases/deeproute-raises-50-million-in-funding-to-research-and-develop-autonomous-vehicles-300932621.html

sensors don't work properly, ensuring the safety our passengers and others on the road.
- **DeepRoute-Vision:** a vehicle-camera with a high dynamic range, allowing optimal detection performance while also avoiding overexposure—even under strong sunlight—using automatic image adjustment and fine LED flicker-resistance.

Our level 4 full-stack self-driving technology includes all of the self-driving technology needed for AV vehicles. Our customers have the option to implement the full-stack solution or individual modules, which include:

- Multiple sensor options
- High density (HD) mapping and localization
- Premium perception
- Planning and control models for a smooth drive at speeds of 50 mph
- Simulation system that can be tested virtually, which is especially valuable for corner cases
- Cloud technology to improve the efficiency of software development
- 5G remote control module

DeepRoute's second-generation ADS (Advanced Data Synchronization) Controller, DeepRoute-Syntric. The ADS controller can synchronize information from different types of sensors, enabling the perception algorithm to process sensor data aligned in the same standard. In the event that the sensors malfunction, the ADS controller can take control of the vehicle and perform emergency tasks such as braking.

**LM:** Please tell us in detail about the level 4 full-stack self-driving system. We are very interested indeed, of course, in the sensors that are incorporated into the hardware, especially the lidar ones, but the whole system—hardware plus software—is of great interest to our readers. Our readership is quite knowledgeable on the use of GNSS and IMU together with optical sensors as well as lidar, so information on DeepRoute's approach to this is especially fascinating. From your website, for example, it appears that the lidar sensors come from Hesai Technology.

**NL:** We utilize lidar technology from several trusted suppliers, including Hesai Technology, Velodyne Lidar and RoboSense LiDAR. DeepRoute-Sense uses a 64-line lidar, while the lidar on the sides is 16-line. We use eight cameras to collect surrounding color data. For instance, the two cameras on the front of the roof box are used for traffic-light detection. Apart from the sensors mentioned above, there is a GNSS and an IMU. Since we developed our own proprietary ADS synchronization controller, DeepRoute-Syntric, it can be modified to support a wide range of sensor technologies. This allows the vehicle to synchronize information from all different sensors, enabling the perception algorithm to process sensor data with the same standard. The perception module allows the vehicle's planning and control modules to detect surrounding objects and predict their trajectory. Based on this information, the planning control can manipulate the driving operation and send a command to the vehicle to change its behavior. All of the calculations from the perception, localization planning and control systems are running on the computer platform located in the trunk.

**LM:** One of the components of your solution is a HD map. Could you please tell us more about this, please? What are its characteristics and who supplies the map data?

**NL:** The HD map and localization solution offers the precise detail required for driving. These maps have extremely high precision, to the centimeter level, and the self-driving system is like an automated navigation map for human drivers. It also provides detailed information about nearby lanes, traffic lights and speed limits. Our mapping ability can decrease the effect of weak GNSS signals near high buildings in large cities—ensuring that people can navigate safely in urban environments—and we filter out the dynamic information on the road to generate a comprehensive HD map.

**LM:** Another component is artificial intelligence/machine learning/deep learning. These areas have become critically important throughout the geospatial and automotive worlds. What is their role in your software? In this respect, what is

Yangfeng Zhu, chairman of Dongfeng Motor Group Co. Ltd., China's second largest auto maker, after a ride in a DeepRoute-equipped robo-taxi based on one of his firm's vehicles.

your relationship with NVIDIA?

**NL:** Deep learning has played a key role in self-driving software development. The software detects the objects surrounding the vehicle and provides information for planning and control modules. Any incorrect detection would cause critical traffic incidents; this is why using multiple sensors is beneficial. The perception algorithm fuses the data before inference, which makes the detection result more reliable. A DeepRoute paper[2] focused on perception algorithms was accepted by CVPR 2020, the premier annual computer vision event, which is a nice recognition of our advanced technologies. Additionally, DeepRoute's HVNet technology ranked highly on the KITTI Vision Benchmark Suite; this benchmarking suite is one way to put self-driving technologies to the test and better understand how different solutions fare when identifying different types of objects. DeepRoute is also a member of NVIDIA's Inception Program, and NVIDIA's Jetson AGX Xavier is used in our current computing platform.

**LM:** What is special in the DeepRoute offering that places it ahead of its competitors?

**NL:** DeepRoute provides safe and reliable solutions to our customers. Our perception algorithm has been ranked highly on the KITTI and Semantic KITTI tests and holds the prestigious recognition of being a CES Innovation Awards honoree. Our highly integrated solutions make it easier for companies to develop and roll out self-driving vehicles and implementations, while also allowing customers to customize solutions for their specific needs.

**LM:** Your business model is centered on the idea that you are a "tier 1 supplier to OEMs and mobility and logistic companies". What does this mean? How do you market your products? Do you do direct sales or do you have a distribution network? *LIDAR Magazine* has learned, through interviews with other leading companies, that relationships with customer organizations are very important, because they can help proselytize and sell your products. Is that true about DeepRoute?

**NL:** Our business model focuses on the robo-taxis industry, one of the most promising verticals within the autonomous vehicle market. We offer a full-stack level 4 self-driving solution to automotive OEMs, tier 1 companies, and mobility and logistic companies.

We have partnered[3] with Dongfeng Motors Corporation Technology Center to co-develop a type of robo-taxi to help people safely navigate around cities. We have also partnered with other large mobility companies in China this year

2 https://openaccess.thecvf.com/content_CVPR_2020/html/Ye_HVNet_Hybrid_Voxel_Network_for_LiDAR_Based_3D_Object_Detection_CVPR_2020_paper.html

3 https://deeproute.ai/en/cooperation/

DeepRoute-equipped self-driving truck for moving containers.

and will be testing several robo-taxis together to prepare for their deployment.

This past May, we partnered with a container terminals company of Cosco Shipping in China to equip its container trucks with DeepRoute's self-driving solutions to automate operations in the Xiamen Ocean Gate Container Terminal. The self-driving truck helps to streamline the terminal's loading and unloading process. We value every relationship with our partners and carefully consider the specific requirements for different self-driving use cases. By carefully listening to our customers' needs for their desired implementations, we're able to accelerate the deployment process and set our customers up for success as they test out their vehicle fleets[4].

**LM:** Do you perceive your market as global, or is it mainly China and U.S.?
**NL:** DeepRoute is a global company and we have developed business partnerships in Australia, China and the U.S., in addition to other regions.

Self-driving vehicle with DeepRoute's technology

**LM:** Last October you were successful in receiving formal permission from the California Department of Motor Vehicles to test autonomous vehicles in the state. Do you feel this shows strong trust in your company and its solution?
**NL:** We were pleased to see that the California DMV granted us permission to conduct tests in the state, demonstrating their trust in our solutions. As Silicon Valley has become a hotbed for automotive innovation, we see that region and California at large as a major market for our technologies.

**LM:** As you enjoy success and adoption of your product grows, you must face the challenge of scaling up production. Does your solution scale well? What are your thoughts about mass production?
**NL:** We are now preparing for mass production and the standardized evaluation of our solutions. Thanks to our leadership team's vast experience in this industry, we specifically designed our hardware for the manufacturing requirements of mass production. Our software was also designed for deployment at scale.

**LM:** What are DeepRoute's plans for the remainder of 2020 and for the further future?
**NL:** We will continue to develop and refine our solutions and expand our business partnerships. We are working towards commercializing self-driving vehicles with our innovative technology that offers a strong competitive advantage in the industry.

**LM:** Nianqiu Liu, thank you very much for your time and your detailed answers to our questions. We wish you well with your exciting product and hope to speak to you again as things develop.

4 On August 19, 2020, after this article had been written, DeepRoute and Cao Cao Mobility, a strategically invested business of Geely Technology Group, announced the companies' partnership to advance the design, development and commercialization of Cao Cao's autonomous robo-taxis service. The autonomous vehicles, powered by DeepRoute's innovative self-driving technology solution, will be deployed at the 2022 Asian Games in Hangzhou, Zhejiang, China. Cao Cao will integrate DeepRoute's new full-stack self-driving system, including its second generation sensing system, DeepRoute-Sense II, into its dedicated fleet of Geometry A fully electric vehicles at the multisport event. Thus DeepRoute has relationships with two of China's largest vehicle manufacturers. The full announcement is at https://lidarmag.com/2020/08/18/cao-cao-and-deeproute-form-autonomous-driving-partnership-ahead-of-hangzhou-2022-asian-games/.

**Stewart Walker** is the Managing Editor of the magazine. He holds MA, MScE and PhD degrees in geography and geomatics from the universities of Glasgow, New Brunswick and Bristol, and an MBA from Heriot-Watt. He is an ASPRS-certified photogrammetrist.

***Graham,** continued from page 48*

EVO ecosystem as a "guest" sensor (we already support the Phantom 4 RTK in this mode). I think it may fit quite nicely at the entry level in our 3D Imaging Sensor (3DIS®) product line. Of course, that is fine, but it still does not answer the question of applications for which this sensor will be suited.

For the past two years, I have been evangelizing the value of RGB colorized 3D point clouds or "3D Images" (3DI). High-accuracy 3DI are incredibly valuable in traditional lidar processing workflows for identifying features during classification. But 3DI are also an extremely useful tool for simple visualization tasks. Suppose I want to monitor a construction site on a periodic basis. I can use photogrammetry but this means I face hours of "image to point cloud" post-processing and, when this is complete, I have a point cloud that does not model a lot of construction features very well (wires, pipes, beams, etc.). 3DI from a lidar sensor with a matched camera system (and, of course, good post-processing software) is the answer. As a side note, it is important to appreciate that 3DI are not lidar points colorized from an orthophoto: these would be "2.5 DI" since an ortho can represent only a single Z color at each X, Y point. A true 3DI has to be constructed by ray-tracing each lidar point to the "best" image that sees that point.

An example of a 3D image collected using a GeoCue True View 410 system is shown in **Figure 2**. Not only does the colorized lidar approach provide a much more detailed scene depiction than photogrammetry, but the post-processing occurs in minutes rather than hours (it takes about 10 minutes to post-process a 15-minute flight).

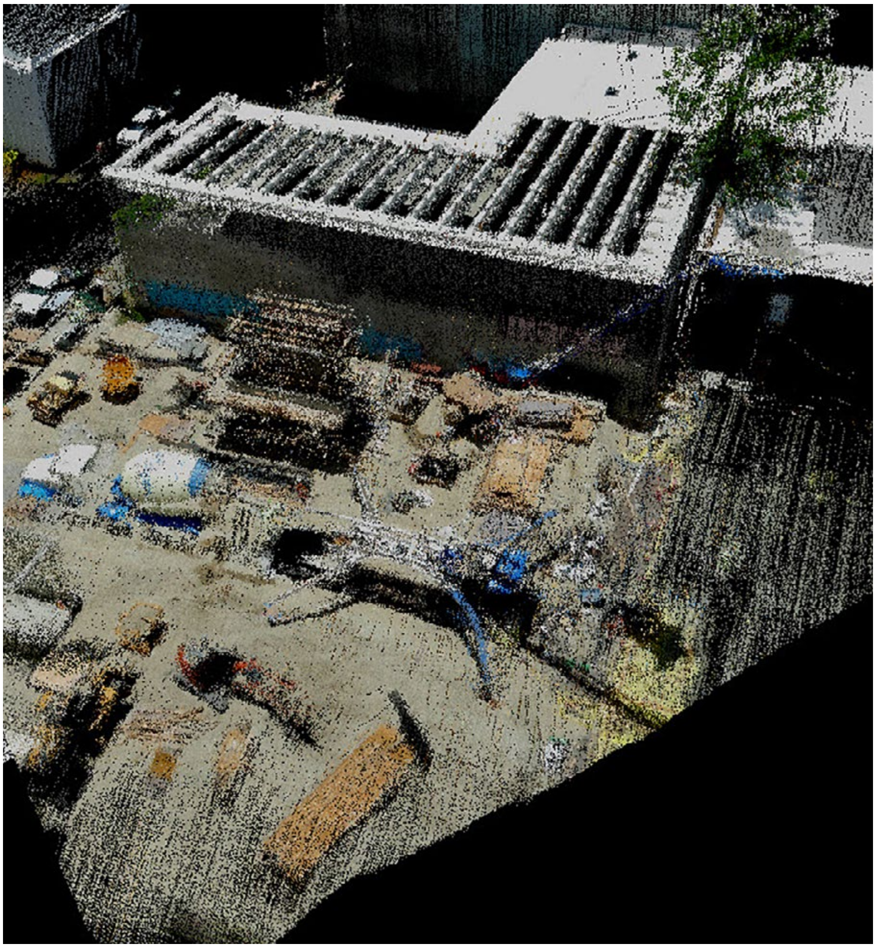
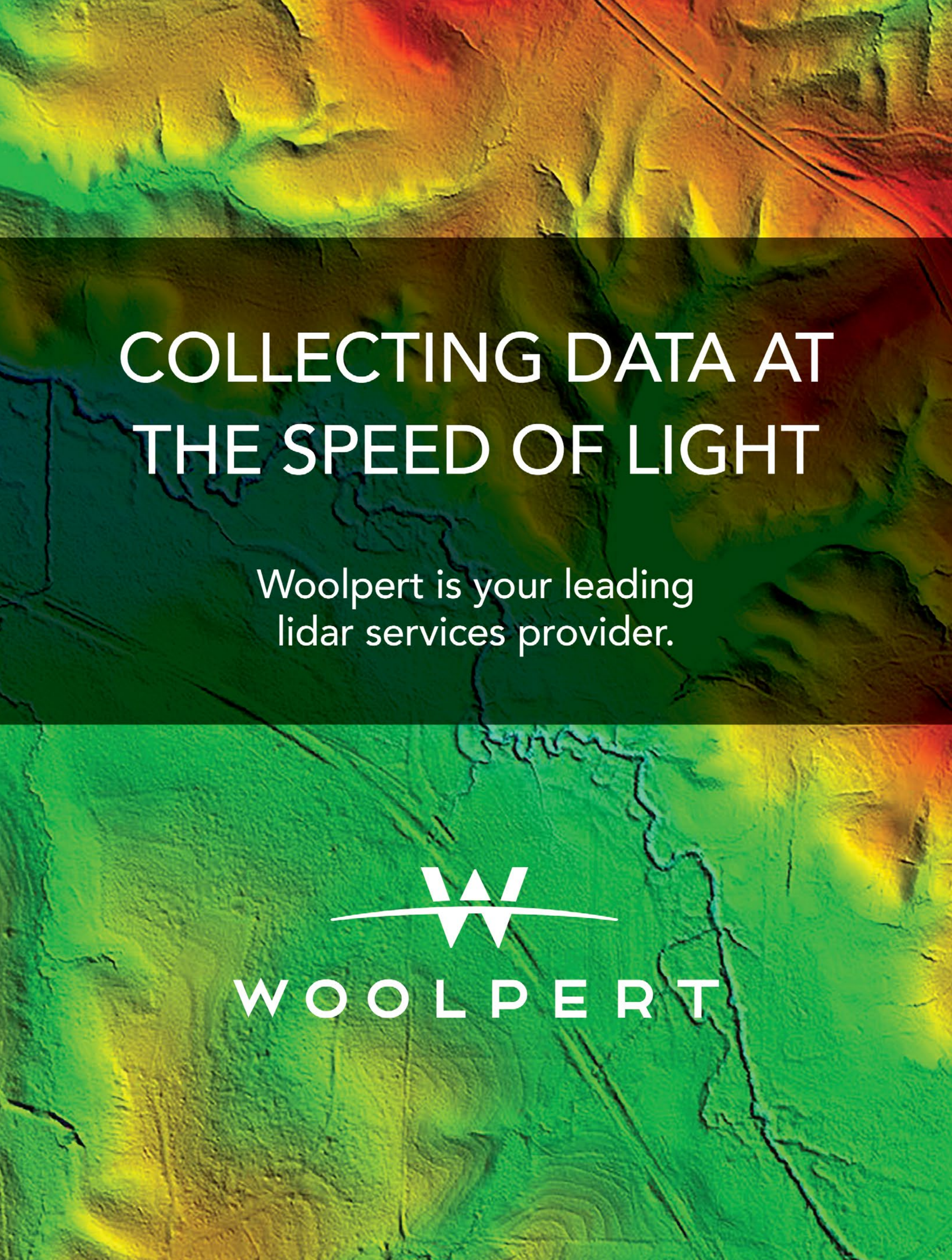


**Figure 2:** Construction site 3DI

Up to now, the ubiquitous use of 3DI for inspection has been hampered by the high cost of fused lidar/camera systems. We (the folks building these systems) have been so concerned about meeting a minimum threshold of network accuracy and high precision that we have not enabled systems aimed at inspection rather than higher accuracy survey. The new DJI L1 is clearly filling that gap.

I truly do believe that this sensor (and others sure to follow) will change the way we do inspection operations. Look for a host of new downstream applications that consume these data as the foundation of visualization and inspection products. Of course, we will provide a review in *LIDAR Magazine* as soon as we have our hands on the Zenmuse L1.

**Lewis Graham** is the President and CTO of GeoCue Corporation. GeoCue is North America's largest supplier of lidar production and workflow tools and consulting services for airborne and mobile laser scanning.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LEWIS GRAHAM

# Has Lidar Viz Come of Age?

The nice thing about hardware is you can pick it up, feel its heft, move it around in your hands, scare the booth folks who think you are about to drop their only sample,… Not so in our new covid age: now we experience *virtual* everything. Among the product buzz of the recent virtual Intergeo conference is the new DJI Zenmuse L1 lidar/camera system shown in **Figure 1**. The L1 features a MEMS lidar scanner from DJI subsidiary Livox, a 1” mechanical shutter RGB camera and an intriguing grayscale camera used for aiding inertial measurement. The entire package is mounted in a three-axis gimbal. The L1 is currently compatible only with the also relatively new DJI M300 RTK drone. Official pricing has not yet been released but rumor is a list price of US $18,000 (sensor only). The primary question from folks who have looked over the L1 specs has been, “What can you do with this type system?”

My company, GeoCue Group Inc., is a DJI Enterprise dealer but demo deliveries to dealers of the L1 are not slated to occur until the end of this year. Thus I can only speculate on the system at this time. I think DJI themselves are struggling a bit with the operational characteristics of the system. In a recent presentation, I saw three different numbers for network accuracy (erroneously referred to as “absolution” accuracy). Given our own experience in evaluating Livox scanners, I am thinking the numbers I saw, 10 cm network accuracy at 50 m above ground level, are probably in the ball park. We do not yet have sample data, so I cannot comment on the precision of the system (i.e. the planar hard surface deviation).


**Figure 1:** DJI Zenmuse L1

DJI have agreed to work with GeoCue to integrate the L1 into the True View

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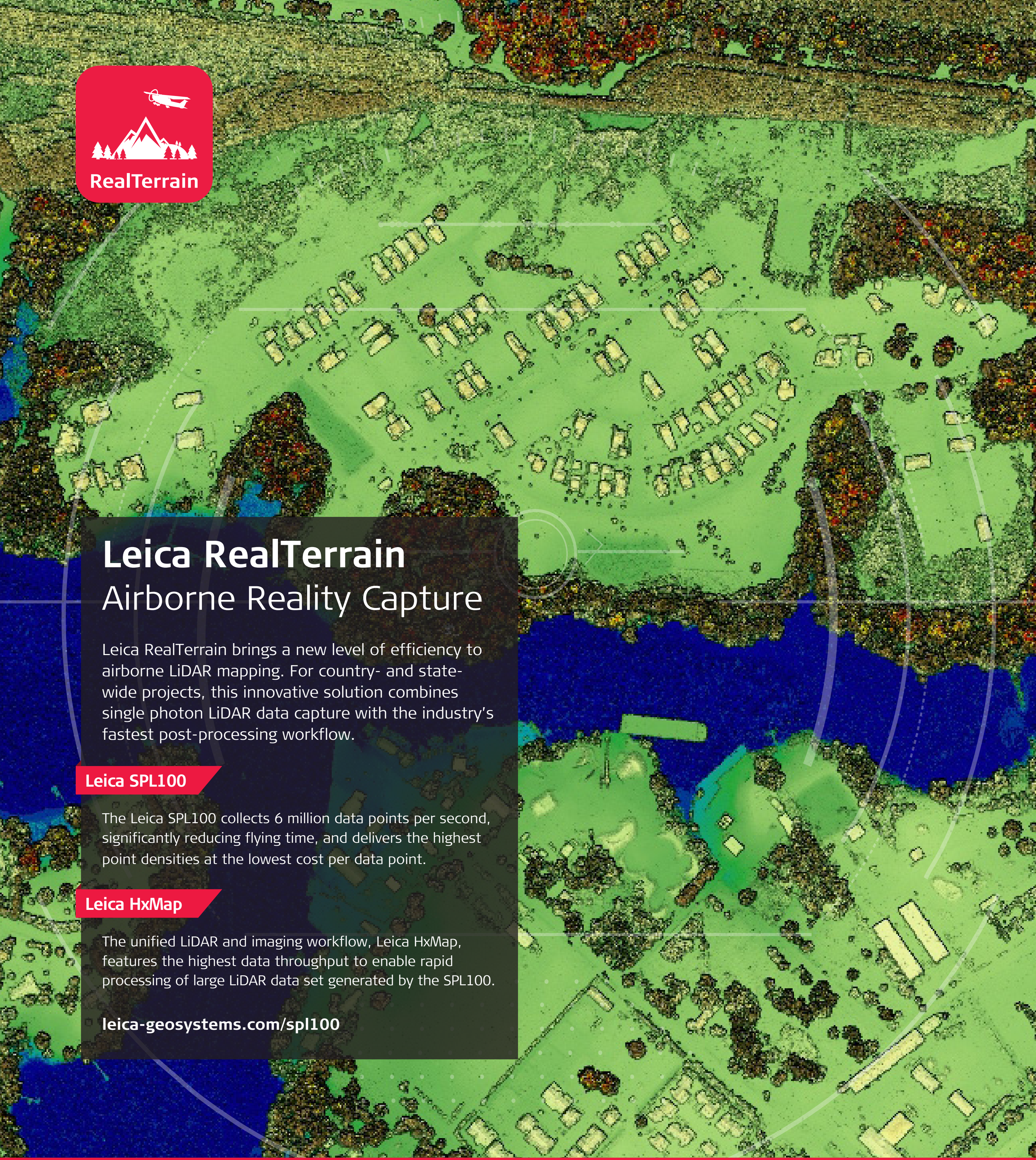
RealTerrain
Leica RealTerrain
Airborne Reality Capture
Leica RealTerrain brings a new level of efficiency to airborne LiDAR mapping. For country- and state-wide projects, this innovative solution combines single photon LiDAR data capture with the industry's fastest post-processing workflow.
Leica SPL100
The Leica SPL100 collects 6 million data points per second, significantly reducing flying time, and delivers the highest point densities at the lowest cost per data point.
Leica HxMap
The unified LiDAR and imaging workflow, Leica HxMap, features the highest data throughput to enable rapid processing of large LiDAR data set generated by the SPL100.
leica-geosystems.com/spl100