VOLUME 9 ISSUE 6

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WINTER 2020

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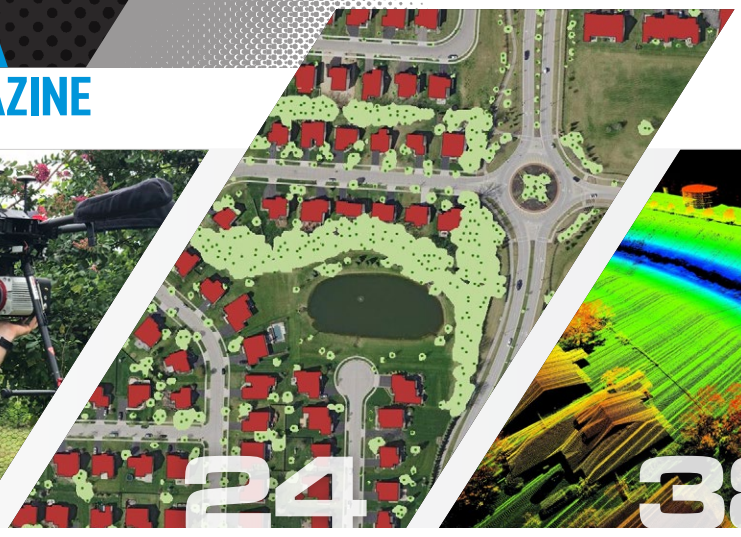

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Artist's rendition of airborne lidar mission. Lidar-derived digital elevation model over Zion National Park, Utah.
Credit: Jason Stoker, USGS.
King Air 250 (airplane) courtesy of Textron Aviation.

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DR. A. STEWART WALKER

So much to read, see and learn!

In addition to the contributions of valued partners and customers to our annual *Aerial Showcase*, this issue includes articles that are exemplars of what I believe are some of the strengths of our magazine. We lead with a piece about LiDAR USA, one of the firms that epitomizes the strength of the UAV-lidar integrators. It is led by a charismatic, talented president, Jeff Fagerman, who travels the world, yet it is still a family business located in rural Alabama. Precision Aerial Compliance Solutions, the firm featured in the piece by its CEO Scott McGowan, a former Wall Street trader who now makes a living in UAV-lidar, owes much of its success to a close relationship with Phoenix LiDAR Systems, a Los Angeles-based UAV-lidar integrator led by Grayson Omans. We have previously written about another UAV-lidar integrator, Geodetics in San Diego, and we are working on an interview with YellowScan in France. The two papers from Woolpert argue to a theme I have highlighted before: the capacity and versatility of the US geospatial services companies is amazing—they seem able to take on projects that are challenging in terms of size, location, deliverables and deadlines—and succeed, again and again. Larry Trojak's piece about Euclideon underlines that visualization is key to many lidar users. And Florian Rebeyrat's Leosphere contribution about wind lidar describes an unusual application, something beyond the geospatial ones that we know so well. Indeed, just recently I read an article—in the liberal elite press again!—about the notion of an aircraft slipstreaming on the wake of the aircraft in front, as happens with a flock of geese[1]. How does one ensure that the following aircraft finds the advantageous part of the wake and not the nasty bit that involves downdrafts and danger? Lidar, of course!

I've tried to provide reports on most of my travels for our digital issues on the website, lidarmag.com, but as the year draws to a close and I reflect, I marvel at the privilege it's been to attend so many fabulous events. Geo Week in Denver at the end of January incorporated ILMF and both ASPRS and MAPPS events. Joining Lisa Murray of Diversified Communications at the podium to present the Lidar Leader Awards for the second time was an honor indeed. Events were big and small, in both Europe and the US: Esri Partner Conference in Palm Springs in March; ASPRS-SDSU meeting in San Diego in April; AEC Next/SPAR 3D in Anaheim in May; HxGN Live in Las Vegas and GeoCue True View launch in Nashville in June; Esri International User Conference in San Diego in July; Photogrammetric Week and Intergeo, both in Stuttgart in September; Quantum Spatial Acquisition Summit in Corvallis, Pecora 21/

1 Anon, 2019. Trail blazers: if aircraft can copy the way geese fly, everyone will benefit, *The Economist*, 433(9172): 78, 7 December.

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ISRSE 38 in Baltimore, and Commercial UAV Expo in Las Vegas, all in October. Phew! I've organized user conferences on many occasions, I've seen the mechanics behind events and now is the time to say thank you to the organizers of all these excellent meetings.

2020 will be similar in some respects, different in others. *LIDAR Magazine*'s year begins with hosting a panel discussion on satellite miniaturization at GeoBuiz Summit in Monterey in January. Geo Week will be in Washington, DC in March; AEC Next/SPAR 3D, in Chicago in June; Intergeo, in Berlin in October; and Trimble Dimensions, in Nashville in November. HxGN Live will be manifested in regional events in 2020 but will return to Las Vegas in 2021. We will do our best to cover these and other events for you and tease out innovations and trends that are going to matter.

It seems we're in the big-time now and I don't just mean that Esri is advertising in *The Economist*! Amazon likes lidar. Television viewers will have noticed references to flash lidar in the *Jack Ryan* thriller series and pedants like myself who view all the credits after a movie (and tut-tut while other cinemagoers impolitely file out) will have noticed, at the end of *The Aeronauts* blockbuster, a reference to Lidar Lounge, a UK-based laser scanning company. And on 4 November 2019, *The Guardian* reported that, "Drone-mounted lasers have revealed details of the architecture of an ancient island settlement off Florida's Gulf coast."[2]

Readers will know that I've been scanning my archive accumulated during a 45-year career. Recently, I digitized my collection of Optech brochures and papers. In the late 1990s, the company was aggressive in publishing use cases in various journals, back in the day when RIEGL was getting going but Azimuth Corporation/LH Systems/Leica wasn't yet competitive. How things have changed. Progress doesn't come without caveats, however. Gavin Schrock's editorial in the December 2019 issue of *xyHt*[3] sounds a warning: we have more options and more suppliers than ever before, but we have to exercise due care on how we select and use products. He was talking more about land surveying equipment, but probably there are lessons there for lidar folk too.

Mention of other magazines is an apposite, yet humbling way to end 2019. There is so much more to learn, so much more to read, than I can ever manage. It's always worth glancing at least at the tables of contents of journals that are tangential to our geospatial endeavors. I try to do this with *Photonics Spectra*, a specialist publication on the edge of our field. There's always the chance of an article on something we should know, perhaps hyperspectral sensors, perhaps lidar. The June 2019 issue was subtitled, "The laser issue 1960-2019" and includes interesting history of the technology at lidar's heart, while the November 2019 issue leads with "Lidar: the future looks fly", a focus on lidar in autonomous vehicles.

2020 beckons. So much to read, so much to see, so much to learn. We will try to help you keep up with it all. We wish all our readers a healthy, successful year.

A. Stewart Walker // Managing Editor

2 https://www.theguardian.com/science/2019/nov/04/drone-lasers-ancient-settlement-florida-lidar-archaeology

3 Schrock, G., 2019. Looking forward: the 4th wave, *xyHt*, 6(12): 1, December.

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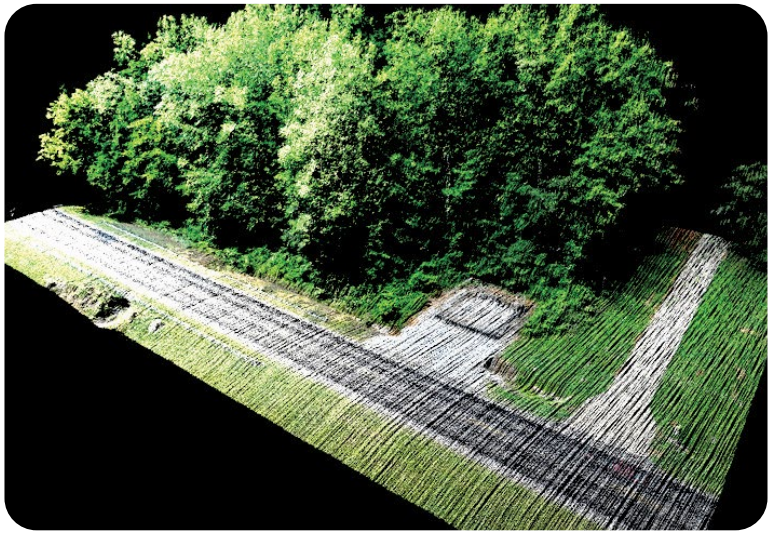

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LiDAR USA Buzzes with Success and Innovation

Alabama integrator-farmer leads the way

Most practitioners in the lidar community know LiDAR USA, an acknowledged leader in the successful integration of lidar sensors on to land vehicles and UAVs. LIDAR Magazine *managing editor Stewart Walker traveled to Hartselle, Alabama to interview founder and president, Jeff Fagerman. Here's what he discovered.*

Driving down a country road amidst rural Alabama's green swards, at the edge of the small town of Hartselle, I spied the sign—Fagerman Farm. Lower on the post, a smaller sign gave confirmation: LiDAR USA. Jeff Fagerman, renowned for his lidar integrations that have sold throughout the world, appeared as I

Above: Jeff Fagerman, founder and president of LiDAR USA. King of all he surveys!

Right: These shots of the main LiDAR USA building and some of the hair sheep underline the growth and rude good health of the Fagerman Farm/LiDAR USA enterprise.

BY DR. A. STEWART **WALKER**

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parked. Equally accomplished as farmer and as lidar guru, Jeff waxed lyrical about a field of sheep quite unlike the ones I am used to seeing in Scotland. They had no fleece! Jeff explained that these are hair sheep, reared for the world's most exquisite lamb. Indeed, his son, Daniel, was in Kansas at a sheep exhibition! Jeff's ambition is to be the provider of these animals to farms throughout North and South America and perhaps his biggest event of the summer was a one-day reception, presentation and dinner for prospective ovine clients. And he will probably accomplish it—I learned over the next few hours that he has multiple successes behind him and several innovative, imaginative schemes racing in his mind.

Fronting the Fagerman Farm compound is a large dwelling, occupied by Daniel and his family. The building behind it used to be the company headquarters as well as Daniel's home. Now it is partly empty, because all the LiDAR USA operations and materials have been moved to a brand new building next

door to the sheep. The living area of the old home, however, now functions as a training center. Beside it I noticed the foundations of another building, which Jeff said would be partly open, like a hangar, and would enable outdoor training to take place even in scorching sun or torrential rain.

We talked about the sort of geospatial topics that excite guys of a certain age, such as the difference between the Purdue and New Brunswick notations for design matrices in least squares adjustments, then settled down in the training area to talk. Jeff had already provided the basic facts and some of his thinking in the interview we had conducted by correspondence (see sidebar). He started by showing me a CNC machine where, early on, LiDAR USA could make its own small parts and save significant outsourcing costs. This is also where he wrote much of the software. There was a big UAV on one wall, and a tornado shelter, as buildings are required to have in Alabama.
The company now has more than 25 employees. Daniel is CTO and Jeff's son-in-law, Forrest Briggs, is COO. Jeff's father passed on ten years ago, but his occupation as Director of Equalizations for the State of Michigan included cadastral and GIS duties, which clearly rubbed off on the young Jeff.

Jeff returned to Purdue to embark on a PhD but didn't say long, discouraged by the role of a graduate teaching instructor, and returned to Intergraph. His experience and contacts stood him in good stead when he left the company to set up a business offering photogrammetric service work, including scanning and triangulation, as well as the medical software he mentions in the interview. The big transition was Daniel's graduation with an MS from Purdue in 2010—the father and son team marching on to the lidar playing field! Jeff had used conventional airborne lidar in his services business, but wanted to do much more. He saw an opening for mobile lidar services, which, like land surveying, couldn't be outsourced as easily as airborne, but was disappointed when he looked for sensors to buy. Topcon, for example, had a system with SICK sensors and Optech had its ILRIS. He judged the StreetMapper to be prohibitively expensive in those days. He evaluated MDL, but the demo went badly. Riegl

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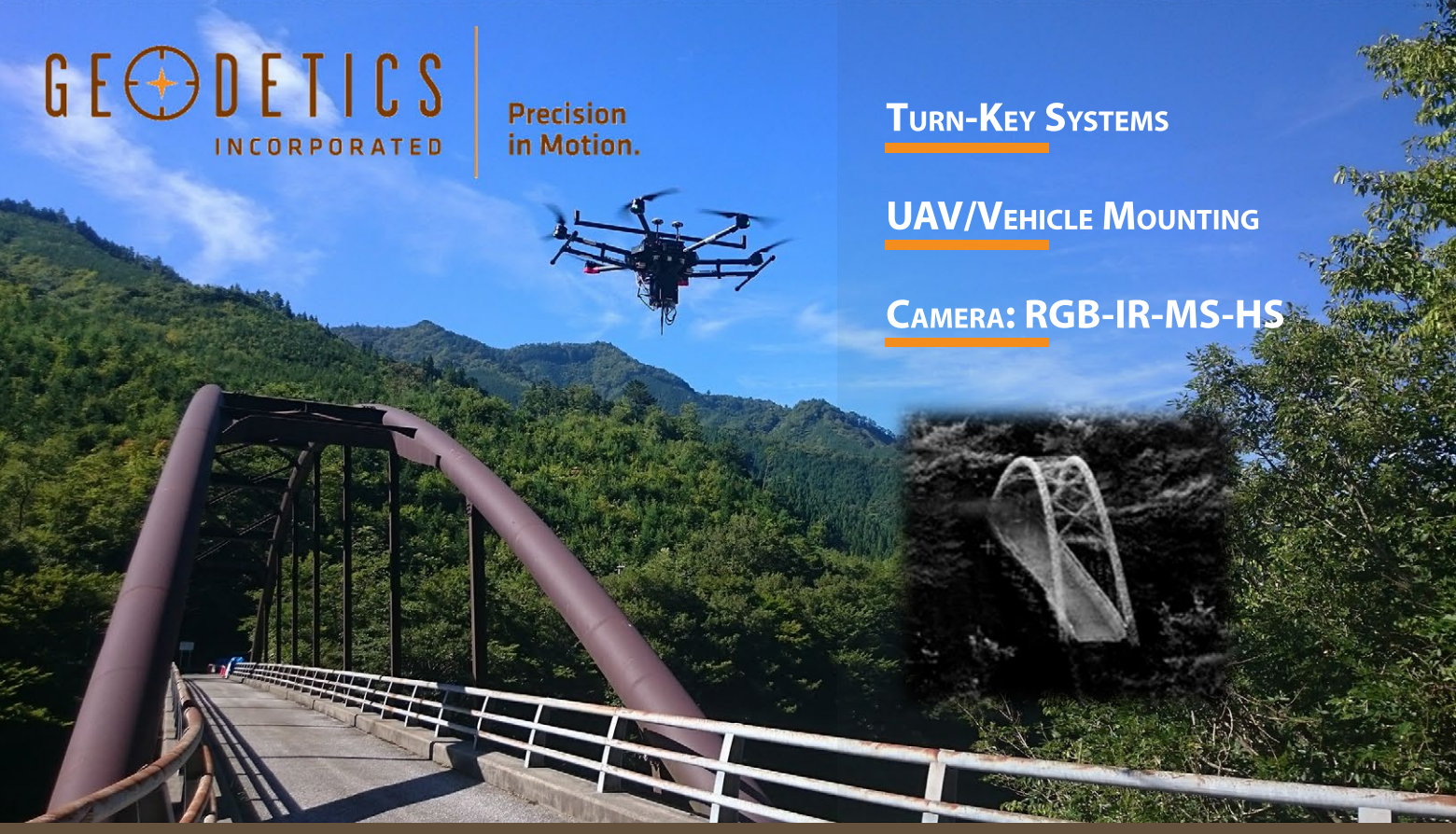

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had a product almost ready, but Jeff didn't want to be first. Topcon was not quite ready with its IP-S2 HD with a HDL-64E sensor from Velodyne LiDAR. And there was little software: Terrasolid and Virtual Geomatics were strong on the airborne side, but the mobile offerings were weaker. Jeff felt that a life in mobile lidar wasn't the way to go.

Things changed, however, around 2010, when Velodyne LiDAR's HDL-32 and the FARO Focus 120 appeared, though of course there was a gap between early product announcements and fully operational systems being fielded. Velodyne was doing DARPA challenges with the HDL-64, but the automotive lidar market didn't really exist yet. Jeff also looked at the Italian firm Siteco, a good choice but a little too restrictive on the type of vehicle, mostly because the FARO Photon was a big device. So he decided to design his own! The Focus 120 changed terrestrial laser scanning—it was tripod-mounted at the then incredible price of $40K. FARO stopped it rotating and Jeff mounted it upside down below the HDL-32. The Focus 120 scanned roads with millimeter accuracy and the HDL-32 captured the assets. He offered services to private companies in the highway mapping space. Jeff even made his own 360° video camera (LiDAR USA still makes the odd sale!), which was a big challenge as it was fiddly to assemble. He acquired an ITAR-restricted LCI-100 IMU from NovAtel. This was a big investment—and so was the five-camera system he also bought. He discovered that there was no warranty protection against customizing the equipment—a salutary experience, but it induced caution. There was a personal factor here: Jeff liked to buy NovAtel equipment from Roman Kathofer, who is well known in the lidar world, and this relationship has been fruitful. Jeff wrote almost all the software, with a little help from Daniel. They showed the system on the FARO booth at a show in spring 2011. By now his living room resembled an electronics shop! The Focus 120 didn't work too well initially. Even the NovAtel product had its teething troubles. Debugging and getting everything to work took weeks, then the IMU went back to NovAtel for months and the HDL-32 had issues too! These were worrying times, but he persisted and by 2011 the system was ugly but worked, mounted on a car, and he could sell services.

The Snoopy CL-90 product provides the highest quality data at the most affordable price. The Teledyne Optech CL-90 scanner integrated with the DJI M600 gives an accuracy of 7 mm and a scan width of 170 m at an altitude of 120 m.

Galaxy CL-90. The Galaxy Helicopter provides a 45 minute flight time with the Teledyne Optech CL-90.

In a side conversation before we began to discuss the products, Jeff lauded many of the other UAV-lidar integrators and stressed the importance of a healthily competitive market to

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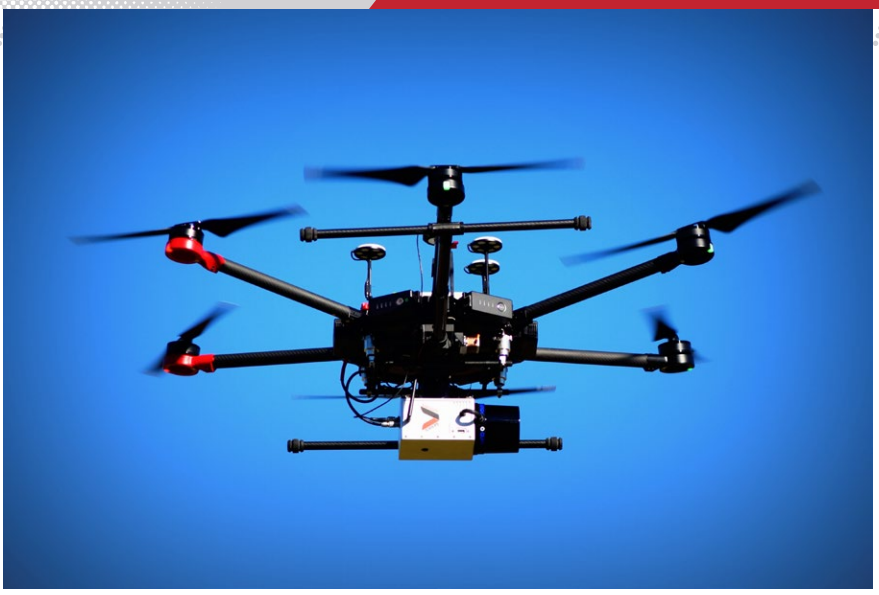

Revolution 120. The Quanergy M8 scanner, mounted on the DJI M600, can capture 100 acres of data in just one flight. It has the ability to provide 3.8 cm accuracy at an altitude of 50 m AGL.

ensure the advance of the technology and the serving of the best interests of the end-users.

His interest in UAVs was aroused in 2012, at the first FARO conference in Orlando, Florida. He met Chris Lord, who was involved with power parachutes and gyro planes, but, sadly, died in an accident in 2018. Chris suggested putting a system on one of his vehicles and Jeff agreed. Chris brought a power parachute, which had a go-kart underneath. They put their one and only system on it. Off it went across a rough field! It carried two people—Daniel and Chris. They scanned a big area and proved the concept. Then Chris and Jeff considered a gyro plane. They were still thinking of service work. The gyro plane couldn't hover, but could fly low and slow at a low cost. The new NERC regulations on US powerlines were a major driver and some surveys were done with Chris's gyro plane.

Jeff and Daniel saw what Phoenix LiDAR Systems was doing with Velodyne scanners and UAVs at an ILMF conference in 2014. They were well aware of the potential of these craft, which had not yet exploded on to the civilian geospatial scene. People were talking about UAVs, but the US regulatory environment was not empathetic: FAA's "333 waiver" process did not begin until 2014 and was laborious. In Jeff's opinion, the UAV-lidar environment was transformed by two things: the introduction by FAA of the Part 107 process on 29 August 2016 (LiDAR USA took a UAV to the ILMF conference earlier that year), and the launch of the DJI M600 UAV [of which there seemed to be units in all Jeff's buildings!], which could carry sufficient payload to handle lidar sensors. Yet he was well aware of the difference between his ongoing, conventional photogrammetric projects and the small areas that UAVs could cover, a point still not fully appreciated in the mapping community. Jeff and Daniel quickly saw that aerial surveying using a helicopter at $350 per hour would be realistic, especially over urban areas and would be competitive with UAV-lidar. They repackaged their system for UAV integration. Jeff explained that systems for use only on road vehicles are more expensive, because they incorporate GNSS/IMU systems with higher performance than UAVs require, whereas users want to switch the system between different kinds of platform—UAV, road vehicle, tripod. Therefore there's more profit from an MMS unit. GNSS is available all the time on an aircraft, but not a car, so a very expensive IMU is essential. So by the end of 2016, Jeff was in—he was a UAV player! Customers also buy systems from him for backpack and road vehicles. Most competitors don't offer such easy transfer between platforms. The autopilot of a UAV is satisfactory for flying the flight plan, but is not part of the data that is collected, which needs a higher performance GNSS/IMU set-up. Jeff resells UAVs and he's also a reseller for Velodyne. He integrates *RIEGL* but is not a reseller.

The first product became LiDAR USA's ScanLook, named because Jeff called the medical software MedLook. Most of the time they call it Snoopy. Jeff has always been heavily involved in product naming and in this case his rationale was that the product did not look like Peanuts—a cartoon character popular in the US but less well known elsewhere—but looked like a dog and snooped.

Jeff also developed his Matrice line of products specifically for the DJI Matrice, which carried a lesser payload than the M600. Only LiDAR USA and Emesent, with its Hovermap, cater for this platform. Jeff resells the SLAM-dependent Hovermap. The A-Series and Revolution product lines series are the same except for firmware options: Revolution is built for UAVs and knows that it will have good position and attitude estimates, leading to some

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cost-saving short cuts. The ScanLook Trex series is the same, but is aimed at Trimble customers, who want to use the Trimble software they already have. Jeff coined the name through an amalgam of references to T-Rex, Trimble and Applanix. The Phase One products are available with the popular Ronin mount, but Jeff makes and sells a better one. After racing through all his product lines, Jeff explained that one of his company's strengths is its ability to integrate a very broad range of lidar sensors, for example from Cepton, Ouster, Quanergy, *RIEGL*, Teledyne Optech and Velodyne.

Although LiDAR USA provides its customers with third-party software for processing GNSS/IMU data, for example Applanix PosPac or NovAtel Inertial Explorer, all the other software is homegrown, so that's another unique aspect—the firm's owner is the software developer. The software creates a georeferenced point cloud corrected with ground control points. The output then moves to the customer's preferred solution for the generation of end-products, for example, Autodesk, Global Mapper or TopoDot. These products also perform point classification and generate deliverables. Jeff would like to take his software further, but doesn't countenance the reinvention of functionality. His goal is to supply fast, reliable software for the critical aspects, then defer to the specialist producers. For imagery, LiDAR USA offers Ladybug, which is fisheye and panoramic, and other cameras, so that lidar point clouds can be colorized.

I asked Jeff about customers' preferences in terms of payment models. US customers typically buy outright, though occasional users like to rent. The pricing is interesting,

Snoopy VUX. The Riegl VUX-1UAV, mounted on the DJI M600, is a compact and lightweight laser scanner, meeting the challenges of emerging surveying solutions. It has the capability to capture 10 mm survey-grade accuracy.

because lowering the price doesn't make a difference—many products exhibit demand inelasticity. Clients in the low-end market have less expertise, as he learned in the medical market.

Although our conversation focused on UAV-lidar, it was impossible not to be aware of, and admire, Jeff's widespread skills. We drove to lunch past the sheep, then, along the road, he pointed out another property he owned. This was purchased for a specific reason: it is at the edge of the service area of the local internet service provider, whereas his compound is outside. So he purchased the property and connected it to the compound using two tall masts and powerful antennae. But it has another use—as a residence for trainees! Although Jeff has left the medical software behind, he is very open to new ventures, one of which is a machine to wash solar panels, which will address a rapidly growing market.

We went on to the recent report from Global Marketing Insights and the prediction that revenues from UAV-lidar in the US will catch up with airborne by 2025. Jeff concurred. We talked about precision agriculture, measuring crop heights etc. and Jeff said that some of his customers are doing exactly that. One customer uses the system over clear-cut land, where some trees are left: they scan, to find the obstacles, then a UAV goes out and shoots pellets into the dirt, i.e.

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We turned to mergers, acquisitions and so on. He has numerous relationships, but no plans for joining up with another entity. He would sell his company if the price were enormous—he's not short of other things he wants to do! He feels LiDAR USA could grow rapidly, but effective selling and marketing around the globe is not easy. He resells sensors (Velodyne, Hovermap), UAVs (DJI, Inspired Flight) and GNSS equipment (CHC, North Surveying). His Alabama location is special and he doesn't want to compromise. Previous premises were in downtown Huntsville, then near Huntsville airport, then halfway home, now he has come home. Many of his employees are local.

"Daniel and Forrest are absolutely critical for me", said Jeff, pointing to Forrest's extensive experience in hospital management. He even does the advertisements for LiDAR USA. His other son-in-law was even better, thought Jeff, but elected to follow his chosen career of school-teaching. Jeff's commitment to educational excellence and the improvement of facilities, as well as parental support, was palpable.

"Some people don't believe you can capture really good data with an automotive lidar, but you can," contended Jeff. His reseller in Atlanta managed 5/100 of foot, i.e. less than an inch, with good ground control points. We agreed that the bulk of the error budget is in GNSS/IMU, i.e. even if the laser were perfect it wouldn't make a huge difference. Jeff has no doubts about the merits of ground control points: for most projects they are essential, but sometimes relative accuracy suffices—it's a matter of understanding requirements. And customers should not underestimate the importance of correctly transforming into the final, local coordinate system: ground control points offer protection against errors in this critical phase.

We ended with a tour of Jeff's spacious new building. On the way, we couldn't avoid talking about the bleating flock! The sheep are on raised platforms, so they push everything through and lie on clear floors. It's more healthy for the animals, who enjoy a balanced, sophisticated diet. The farm uses Excel pivot tables to assess their rams' performances.

We passed the foundation of the latest, hangar-like building, started the previous day, a decision having been made the day before that. We went into the new building and started by looking at his massive inventory. The building is specially insulated so the valuable goods will not be compromised. A vehicle can be driven in, but the inventory prevents it! There were shelves of batteries, piles of M600s, backpacks, M200s, GNSS systems, various Velodynes, Quanergy systems and others. He thinks his competitors don't hold so much, i.e he prides himself on having the components. "If we have it, we can sell it. Customers want it yesterday." A room supposed to be saved for his grandchildren's language lessons (German from their FedEx driver, Spanish from their live-in Venezuelan veterinarian) was expropriated by Jeff's daughter to print tee-shirts, hats etc. LiDAR USA's orange trainers for show staff have been noticed round the globe. They have a photo lab and both conventional and carbon-fiber 3D printers. There was space for finished products. Several *RIEGL* systems were awaiting integration, bought early as there is a very long waiting list. Jeff's office location lets him view all the main activities as well as the arrival of delivery trucks—if they come late at night, he's still there. I spoke to a happy intern from a local school. Jeff showed me M200 systems and the mount for the lidar unit—an integration unique to LiDAR USA. He had a Teledyne Optech CL-90—the integration is ready to go. Jeff enthused about a Z+F system for land vehicles. I remarked that he seemed able to get any sensor and integrate it successfully. Has has done a bigger range than anyone else. Also they have learned to be quick at assembly. If a lidar sensor is expensive, then the integration can take longer. He broke off to talk to a neighbor about a goat pen for the back of a pickup truck. He will sell a system before he knows he can build it, because he is confident he can do it! The software doesn't need to change very much. They talk to the sensor manufacturers about what they can do while maintaining the warranties. Mike, "a master-tinkerer" according to Jeff, had just finished a *RIEGL* VUX system for a UAV or a car. Every system is thoroughly tested, in the lab and in flight. It's all done fast. The universal mount allows systems to go on car, backpack or UAV. There were two backpacks ready to go. Mike said the VUX integration had taken about a week and a half, but there were interruptions—a week would be reasonable. With the more expensive systems, profit is bigger and the VUX is scarce, so optimizing the build time is less important. It looked fabulous. Multiple colors are available. We all liked the black.

We looked at a Cepton sensor, now in its third incarnation. It had changed a lot, opined Jeff, and now works pretty well. He was about to test it. Mike would start it up later in the afternoon.

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Then Jeff showed me the Ouster. I expressed astonishment at the sheer variety of systems. The summer intern is gaining experience that most people would envy! He showed me the Livox lidar from DJI, but DJI now prefers to recommend LiDAR USA, and the Triple-IN from Germany, as well as others I hadn't even heard of! There were NCTech iSTAR and Pulsar360 panoramic cameras, then a huge VTOL UAV from China—this was perhaps the first one exported.

Just before I left, Jeff showed me his new conference room, so they can have meetings even when training is going on. This ended a remarkable, informative day. Not only is LiDAR USA a company acknowledged as a successful, international supplier of lidar systems for cars, UAVs and other platforms, but it has an unusual location, local flavor and small-business atmosphere. It has strength in depth and flexibility that have enabled a wider range of integrations than its competitors. But behind that is versatility and the desire to address completely different projects and markets, driven by the agricultural background in the family's past. The driving force is founder and CEO Jeff Fagerman, a highly educated, competent surveyor with amazing flair and imagination, amply supported by talented family members and local employees.

Dr. A. 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.

Jeff's Thoughts Up Front

Before traveling to Alabama, managing editor Stewart Walker conducted an interview with Jeff Fagerman by e-mail. Here is what he said.

LM: Jeff, we know you of old. You were well recognized as an ace software designer and developer at Intergraph, where you worked from 1985 to 1999. You came from a farming family in cold, cold Michigan, an upbringing that pushed you towards surveying as a career Your father was an Equalization Director. You have degrees in geomatics from Ferris State and Purdue, the former chosen on the bases of proximity and lower fees. Please tell us about that part of your career and why you left the big corporate world. Then you became a professional land surveyor in the State of Alabama. Readers can find out more on the heartfelt, articulate page https://beasurveyor.com/jeff-fagerman.

JF: Yep, 1985 to 1999 with a short stint back at Purdue from '89 to '90. BS Surveying in '84, later converted to BS Survey Engineering (adding one chemistry class). Both very good schools with good programs and instructors. Mr. Sayed Hashimi stands out as a beacon for sure at Ferris and Prof. Mikhail at Purdue.

Intergraph was great. I got to use the vast majority of what I went to school for—something few can say is true: software, calculus, physics, and of course, geomatics (surveying and photogrammetry). Working with the latest hardware and software was a blast. We had only one competitor (Leica then LH Systems) and I was classmates with one of the key guys there (Kurt DeVenecia). We used to compare notes at conferences and drive our management crazy—as if two little guys can in any way change the direction or speed of the *Titanic* aboard which they found themselves. Wishful thinking. Great job though, very hard to leave. In '99 I had done about as much as could be done with the current hardware and decided it was a good time to strike out on my own. I had always told the VPs at Intergraph that when the system was truly commercial-worthy and affordable I would likely do this—so I did it. It was a big leap of faith with a single income and four young children. My first week at home was the week the fourth kid started kindergarten—no break for my wife, Nancy.

From 1999 to about 2003 the focus was photogrammetric services (mostly aerotriangulation, but also some scanning and orthos), custom software and consulting. This also included sales of BINGO from Dr. Kruck in Germany. If you are going to be a small company, you have to be the *best* and able to do the impossible (so it seems). About that time I also purchased a moribund medical billing and practice management software suite. That was an interesting adventure. I learned a lot about things I'd rather not know (such as filing insurance claims!).

LM: Please tell us about setting up LiDAR USA. Why did you do it and why did you think the timing was just right?

JF: In 2007 I looked at mobile lidar—far too expensive, huge, clunky, etc. The software for exploitation was almost non-existent. I waited until 2010, when my son Daniel finished grad school in civil engineering at Purdue. Now I had a partner. We chose lidar because you can't ship the service aspect overseas—you have to be on site to physically capture the data. After a great deal of research we were compelled to build our own system using FARO and Velodyne sensors. 18 months later those scanners were working. Part of the learning curve was with expectations. I expected the sensors to work when I bought them. New products very rarely do, it seems, and you learn to expect at least a 12-month

period of struggle. In any case, we debuted the system at SPAR 3D under the FARO umbrella. The interest was high, so we spent another year developing our first commercial product. It's a tricky business—if you are too early you lose, or too late you lose. Timing is critical. We spent a lot of time considering the market but we were also lucky and very blessed. Both FARO with the Focus 120 and Velodyne with the HDL-32 "told" us the timing was right.

LM: There are numerous integrators in the market who produce systems that combine UAV, GNSS/IMU, camera and lidar sensor. Please tell us what makes LiDAR USA different.

JF: First, this isn't a secondary attempt or trial for us. This is what we do. We're not just jumping on a wave and hoping we can ride it out. I am a surveyor and photogrammetrist—this is what I do.

Our software is fully functional yet not overly complicated. Nevertheless, there is a tremendous amount of simplification still to be done. There is no other vendor that integrates as many scanners, IMUs, etc. as we do. We are a one-stop shop for mobile and UAV lidar—everything but static [TLS] and conventional airborne [ALS].

LM: Tell us something about the history of LiDAR USA. How has it developed, how many staff, premises, product lines, etc. You have a lengthy, complex product line, so please explain it to us.

JF: 15 to 20 people. Lots of products. We are not yet in the commodity business, so there are numerous custom options.

LM: We have learned from a recent Global Marketing Insights report that the lidar market is likely to grow at remarkable speed from now till 2025. LiDAR USA is clearly well positioned to enjoy this growth. But the report also says that there will be partnerships, mergers, acquisitions and so on as companies jostle for positions to take advantage of the increase in market size. What do you think about this? Will LiDAR USA participate? What partnerships do you have and what others do you anticipate creating?

> "There is no other vendor who integrates as many scanners, IMUs, etc. as we do. We are a one-stop shop for mobile and UAV lidar."

JF: Well, we aren't planning to buy anybody yet. We are growing fast and plan to continue to grow very rapidly, not so much in numbers but in products and sales.

LM: Please take this opportunity to make some remarks about the movers and shakers in your company. I know from experience that successful entrepreneurs are skilled in recruiting good people to work with them. Does this apply to you?

JF: Ah, the hard part of the job—finding the right people. I reared mine and then had them marry in. Personally, since childhood, I have been in business (raising bees, selling honey, truck gardening, etc.). You have to learn how the consumer reacts. Most customers will give you a push on price!

LM: Jeff, it seems that there are several trends emerging in our UAV-lidar world. For example, the enormous automotive market engenders big R&D efforts, which seep into the UAV-lidar world, resulting in cheaper, lighter sensors. Deep learning seems set for a major role in point classification. There has been a debate on formats, i.e. LAS and E57 were the leaders, but vendors such as Esri and Martin Isenburg are involved as well. Indoor lidar surveys are a growing market and it is necessary to marry indoor and outdoor point clouds. On top of all this, Cloud processing is becoming increasingly important. Would you like to comment on any of these trends?

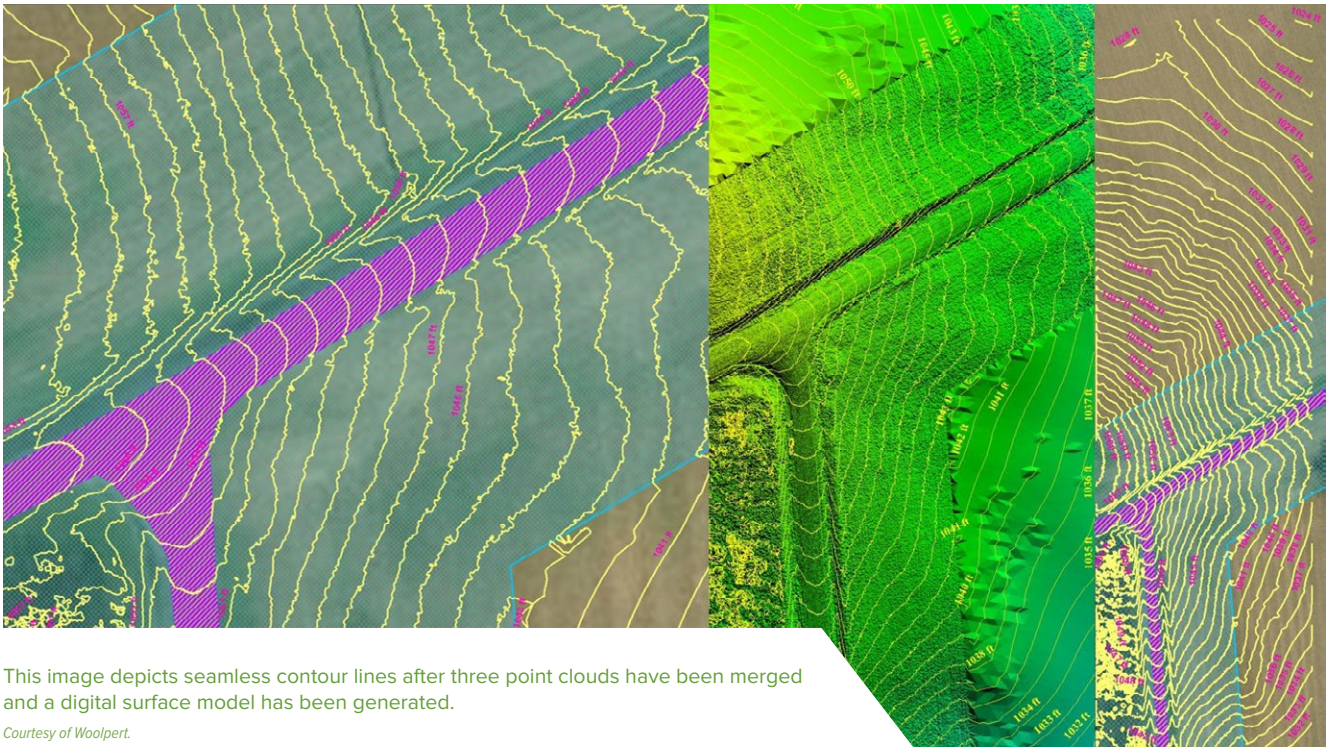
JF: Lots of buzz. As you know, some have buzzed about flash lidar for almost a decade. Where is it? According to their articles it was supposed to be here a few years ago yet it's really no further today than many years ago.

Deep learning is the new rave. Remember the days in the late 80s and early 90s with "snakes" algorithms for automated building extraction, etc? Lots of money chased after that and ended up nowhere. It doesn't mean deep learning isn't real, but don't hold your breath. With all automation, 98% and even 99% is not close enough. The problem with algorithms versus humans is complicated by overseas cheap labor as well. It is coming. We see it. For us, it will only help.

LAS, E57, etc. I really don't like either format but LAS rules. Many vendors have their own internal format but LAS remains the neutral format. It works.

Indoor scanning (or GNSS-deprived) is interesting. On one side we have users who want 1-2 mm *maximum* rmse results, while others accept a couple of centimeters and the majority seem only interested in floor plans. It is definitely a growing market and will undoubtedly be driven by government mandates to map all buildings. I think that's largely a political issue, like so many other things. SLAM solutions will change rapidly and deep learning will likely be a big part of this.

As to lidar, we have two branches in our area: the more conventional high-accuracy, longer range systems (*RIEGL* and Teledyne Optech); and the automotive solutions (Velodyne, etc.). There is no question how well the first does, but there are doubters about the second in terms of mapping. Our customers use both. Those benefiting from the lower cost of the second are enjoying a great ROI.



This image depicts seamless contour lines after three point clouds have been merged and a digital surface model has been generated.

Courtesy of Woolpert.

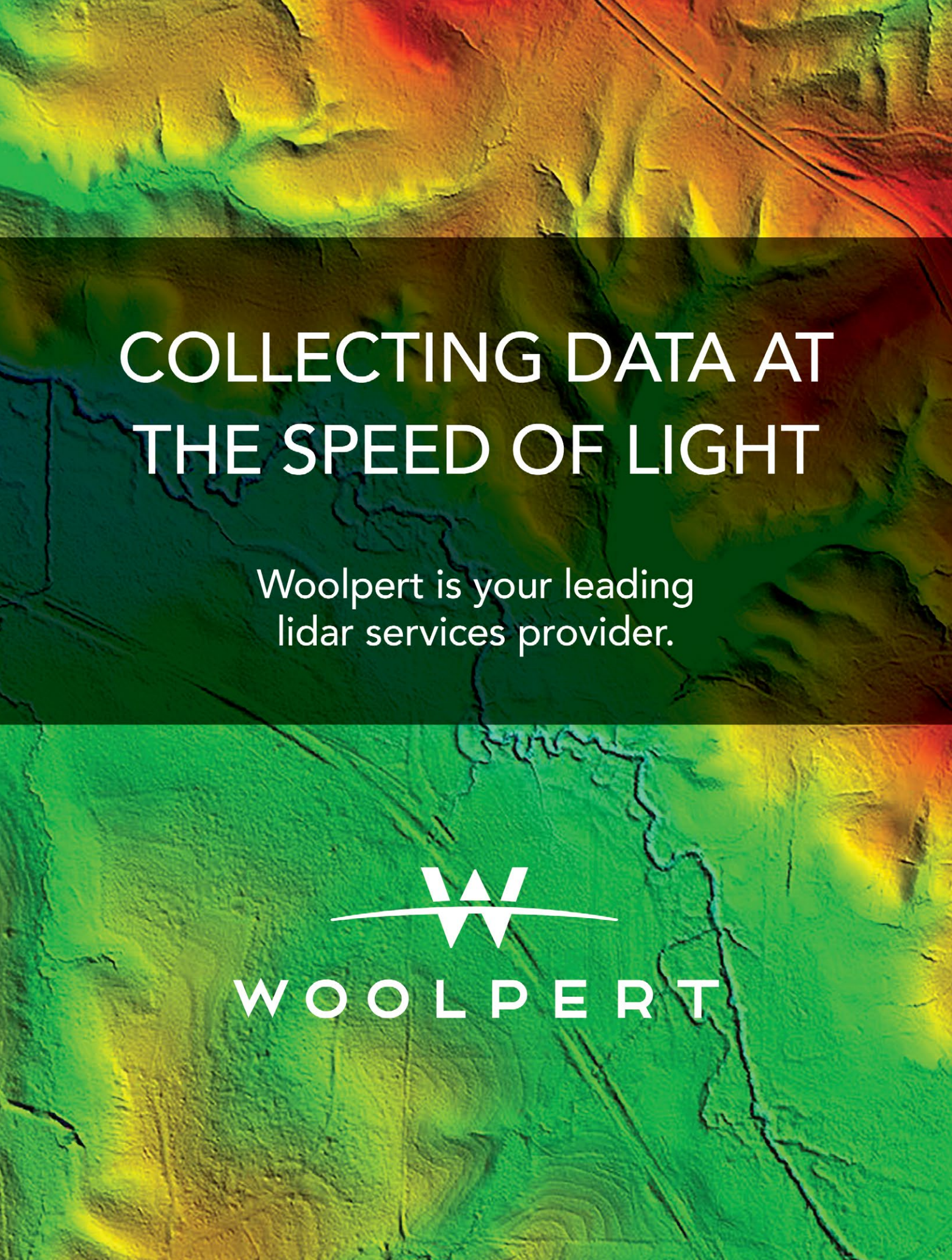
UAS: Get to Know the Newest Tool in Your Toolbox

Woolpert UAS Technology Manager Aaron Lawrence, GISP, discusses why understanding the strengths and weaknesses of drone technology is the key to commercial success.

If you feel every business but yours has a drone, here's why: the market for commercial drones is growing faster than even the Federal Aviation Administration (FAA) expected, it is now forecasting that sales will triple by 2023. In less than a decade, unmanned aircraft systems (UAS) are in line to create 100,000 jobs and add $82 billion to the U.S. economy. These statistics make the endeavor sound tempting, but at least one trailblazing UAS expert suggests you do some research before making that leap.

BY AARON LAWRENCE

Aaron Lawrence, GISP, was instrumental in Woolpert—an international architecture, engineering and geospatial (AEG) firm—becoming the first surveying and mapping firm approved to fly UAS commercially in designated airspace in 2014, through the FAA's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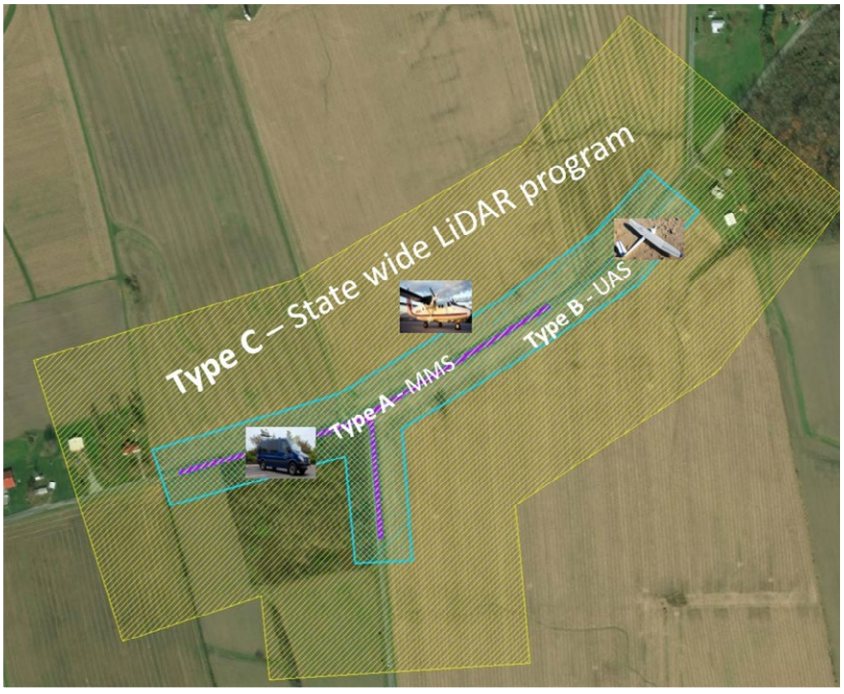


Coverage-area polygons in this image represent the data from three individual mapping tools: UAS, MMS and statewide lidar. *Courtesy of Woolpert.*

Section 333 exemption. Lawrence also became one of the first people in the country to earn his Part 107 Remote Pilot Certificate in 2016 and continues to accrue UAS certifications specific to individual agencies and organizations—most recently for the Pennsylvania Department of Transportation.

For Woolpert, Lawrence performs projects and evaluates technologies for multiple commercial UAS applications, while fostering the firm's growing fleet of pilots. In this Q&A, Lawrence discusses the rise of drones across the industry and shares how to best approach the commercial application of this technology to prevent wasting your firm's time and money—and to prevent compromising the deliverable to your clients.

Q: You have been involved since the beginning of this technology. What has led to this UAS industry boom?

A: Everything's going jet-engine and not many companies are making aircraft like the 1970s-era piston-powered Cessna that could fly low at 100 mph. This has made drones the logical next step for aerial photography. But, as with any professional equipment, don't get one because it's cool or because everyone else is doing it. Drones are just a new way to collect aerial information that happens to be unmanned. Yes, we can see 2.5 mm from 75 feet instead of 10 m pixels; and yes, we're counting rivets on structures and bridges. The capabilities are truly awesome.

But these systems generate huge files that must be processed and analyzed, creating the need for robust data-management software and new photogrammetric workflows. And, in many ways, the technology is still in its infancy. Manufacturers are refining cameras and lasers, and prices are dropping. But just one change in federal regulations—allowing beyond-line-of-sight (BLOS) flight, for example, or drones that weigh more than 55 pounds—could radically alter any organization's program and investment.

Does that mean you shouldn't buy one? Not at all. Just don't expect it to solve all your problems and understand that it will create new challenges. Have realistic expectations: A drone is just one tool in your toolbox. We want our surveyors to have a drone, but we don't expect drones to replace surveyors.

Q: How do you integrate drones successfully into your operations?

A: We approach every job by asking, "What's the most efficient way to collect data that will meet this client's accuracy requirements?" Using just a drone to collect this data is rarely the solution. What you want is to fuse data from multiple sources to get the most accurate picture of reality, so you can make the right design decisions.

Let's take the Highland County Engineer's Office Petersburg/Overman intersection improvement project, which is in Amish country. The point at which these roads converge is an elevated knob, creating a dead man's curve. Drivers coming from the west would travel at high speeds but, due to the bend in the road, couldn't see the buggies turning on to the road.

When the county asked us to investigate the site, our Project Manager Nathan Fischer took a best-of-breed approach. We had year-old lidar data from our (Ohio Department of Administrative Services) Office of Information Technology contract to map the entire state. That gave us 2-8 points per square meter (ppsm) for a 6-15-cm root mean square error(RMSE). That's pretty good, but it doesn't provide surface detail. We used our mobile mapping system (MMS), a van equipped with two Teledyne Optech lidar sensors, to collect data. Now we have 2000-6,000 ppsm for a 1.5-cm RMSE. Then we used a drone—40 to 1,000 ppsm for a 5-15-cm RMSE—to capture what the MMS couldn't capture.

We combined the drone-generated data with the MMS data and the existing statewide lidar to generate a digital surface model (DSM), reflecting the best of breed in data extents, resolutions

Accuracy Term	Processing Scenario	
	D	E
Number of GCPs in AT	5	7
Number of Check Points	28	26
RMSE E (ft.)	0.037	0.014
RMSE N (ft.)	0.029	0.015
Radial RMSE N,E (ft.)	0.047	0.021
RMSE Elev. (ft.)	0.105	0.039
Horizontal Accuracy at 95% (ft.)	0.087	0.036
Vertical Accuracy at 95% (ft.)	0.206	0.077

This is a comparison of two different GCP configurations at our Dayton, Ohio, calibration field and the accuracies achieved by each.
Courtesy of Woolpert.

and accuracies. Ground control points (GCPs) were used to control and independently verify the accuracies of the data from these three sources. This is a good example of why you will always need surveyors and these GNSS inertial measurement units.

Q: If an organization is considering adding a drone program, what can it do to ensure success?

A: Two things: One is technical and the other safety-related. On the technical side, use the American Society for Photogrammetry and Remote Sensing (ASPRS) standards for digital orthoimagery, planimetric and elevation data released in 2014 to develop program specifications. Accuracy classes, based on RMSE values, were updated from the 1990 standard to reflect advances in technology since then.

On the safety side, follow the U.S. Department of Transportation's (DOT) Unmanned Aircraft Systems Integration Pilot Program launched in 2018. The agency is working with multiple state, local and tribal agencies—including the Kansas, North Carolina and North Dakota DOTs—on night operations, flights over non-participants and BLOS, package delivery, detect-and-avoid technologies, and data links between pilots and aircraft. The results may accelerate approval of operations that currently require special authorizations.

Q: How do you assess manufacturers' claims regarding the capabilities of sensors or systems?

A: I automatically knock 20% off the stated flight time because, since they're trying to sell that product, they state what the flight time would be in optimal conditions—sunny with no wind. You're not going to be flying in optimal conditions. If it's too hot or too cold, you'll be sitting in the truck with the air conditioning or heat on.

I also take vendors' accuracy claims with a grain of salt. Woolpert has a drone test site and calibration field at headquarters in Dayton, Ohio, where we verify all manufacturer claims using different GCP configurations. So, when a vendor says, "We can create a 1/10 vertical accuracy with no control," we can say, "Come on over to our site and prove it."

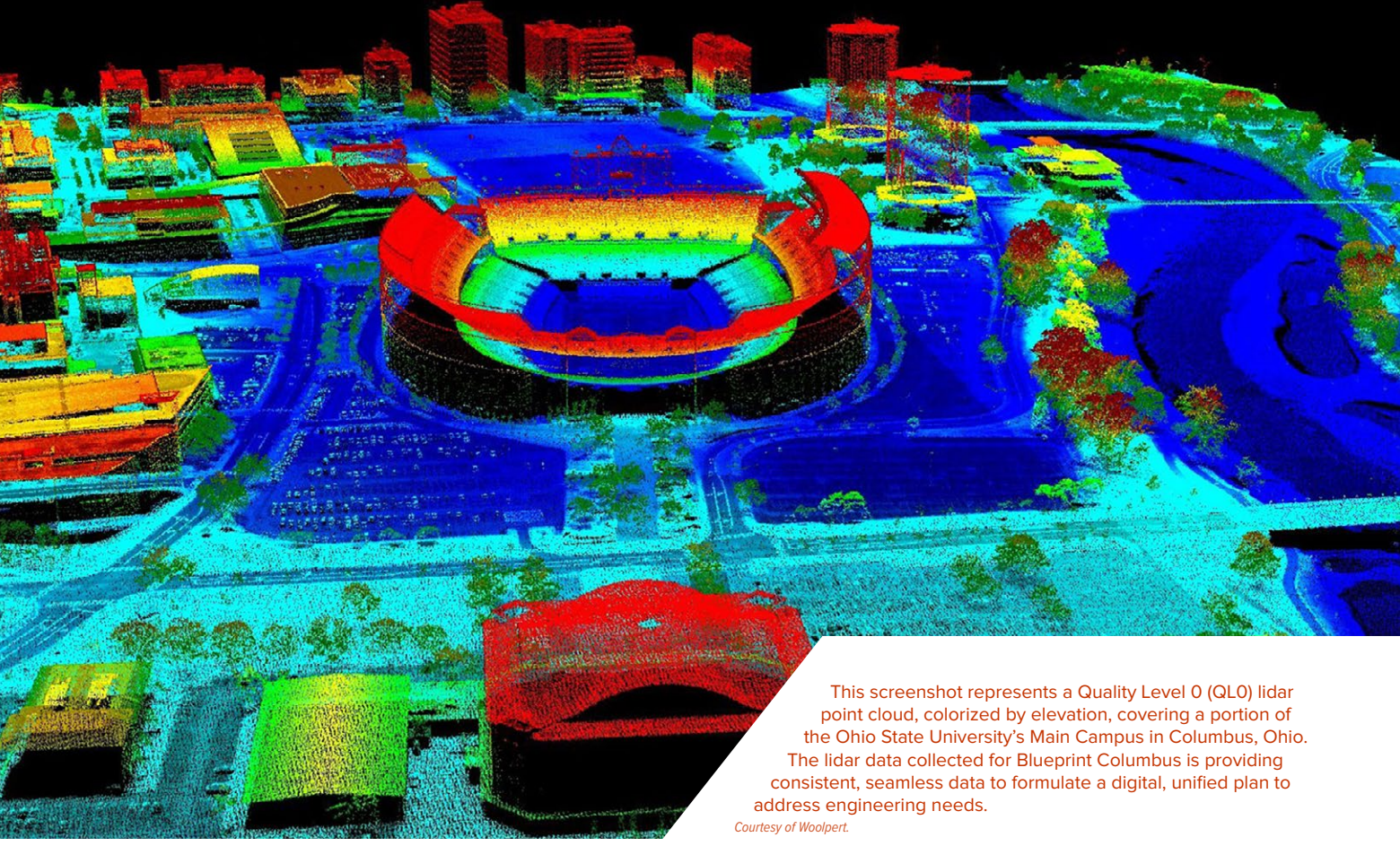
Q: Why are GCPs and the adherence to the standard they set so important?

A: GCPs can help us achieve the holy grail: accurate, repeatable results. We're trying to figure out how many GCPs you need to achieve a specified accuracy. We've achieved 2-cm RMSE, but we haven't quite made it repeatable yet. We're not far off, though, and that's where we're focusing our efforts.

It's this kind of research and development that has become our sweet spot with UAS. Woolpert used to be the ones flying the projects and collecting the data. We still do that, but we've also responded to the demand to share what we've learned over the years in the industry—in UAS, geospatial, survey, lidar, etc.—by helping organizations develop their own drone programs, so their pilots can fly and crunch the data. It's similar to how our role evolved when the industry moved from CAD to GIS: We facilitated the transition by helping organizations manage the data.

By playing this role, we ensure the creation of better-quality data, which will then have expanded applications and lead to groundbreaking solutions. We do this to help this awesome and evolving industry continue to grow in the right direction. I love this medium and learning every day what UAS can do, and I want to make sure it's done right.

Aaron Lawrence, GISP, Woolpert UAS Technology Manager. aaron.lawrence@woolpert.com.



This screenshot represents a Quality Level 0 (QL0) lidar point cloud, colorized by elevation, covering a portion of the Ohio State University's Main Campus in Columbus, Ohio. The lidar data collected for Blueprint Columbus is providing consistent, seamless data to formulate a digital, unified plan to address engineering needs.

Courtesy of Woolpert.

QL0 Lidar Data Provides Highly Accurate Roadmap for Blueprint Columbus

Columbus is the capital city of the state of Ohio, which contracted for its first statewide lidar collection in 2006. Similarly, Columbus is forging new geospatial ground by procuring one of the largest collections of Quality Level 0 (QL0) lidar data. QL0 data is collected at 8 points per square meter or greater, in accordance with U.S. Geological Survey (USGS) specifications.

Blueprint Columbus, an innovative initiative of the Columbus Department of Public Utilities (DPU), applies advanced technologies to direct rainwater out of the sanitary sewer system and into the storm sewer system. The program uses an engineered solution to mimic nature by creating green infrastructure, such as bioswales or rain gardens, to meet stormwater regulations for filtering pollutants, while addressing sanitary sewer overflows into neighborhoods.

The city contracted with Woolpert in 2018 to collect QL0 lidar data over a geographical area of 680 square miles in central Ohio, including downtown Columbus. DPU Geographic Information System Manager Mike Edwards said that the QL0 data, which was collected in early 2019 at 12 points per square meter and with a vertical accuracy averaging two inches, was sought to meet the specific needs of the program.

"The city had collected lidar data at Quality Level 2 point density in 2015, which proved useful for multiple projects," Edwards said. "But a handful of city consultants wanted

BY BRIAN STEVENS

more vertically accurate lidar data to support the creation of highly detailed hydraulic models."

The data is being used to support preliminary engineering for Blueprint Columbus, providing DPU with consistent, seamless data to formulate a digital, unified plan, without sending surveyors into the field.

"A lot of engineering work is performed before construction starts," Edwards said. "The more accurate the lidar data at the outset, the more accurate we can be at sizing our rain gardens, bioswales and regional rainwater detention facilities. And so far, we definitely like what we've seen."

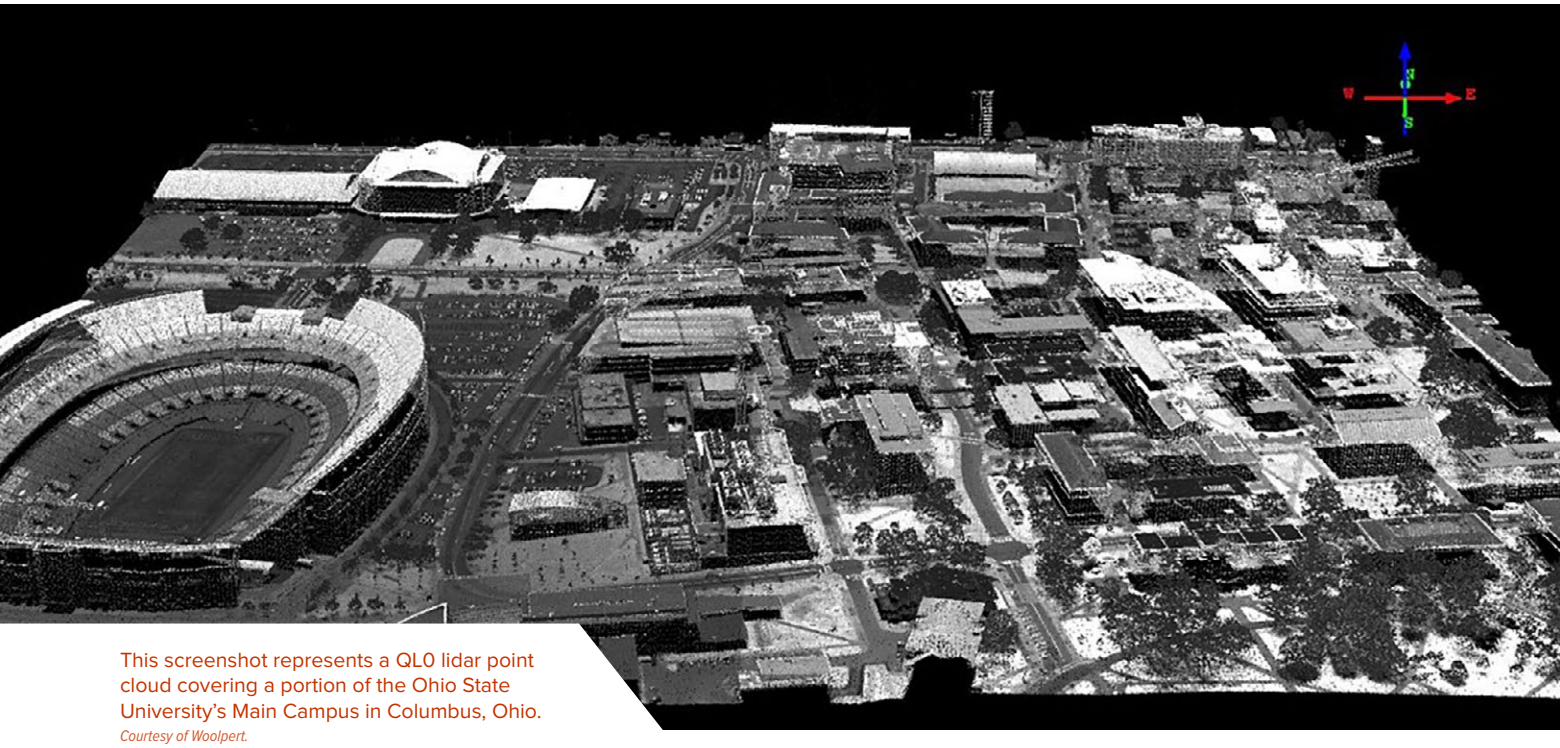
Geospatial history helps outline Blueprint

Ohio has a long history of developing geospatial data and GIS technology to support government services and applications through its Ohio Geographically Referenced Information Program (OGRIP). Since its inception in Columbus 30 years ago, OGRIP has coordinated statewide geospatial initiatives that benefited all levels of government, provided leadership, and promoted the value and application of GIS technology for all programs and departments throughout the state.

As a result, Columbus officials are familiar with the value and application of geospatial data. OGRIP programs such as the Ohio Statewide Imagery Program (OSIP), which was introduced in 2006, is in its third iteration. For more than a decade, the state has provided OSIP as a contract vehicle that allows municipalities to purchase color digital orthoimagery, lidar data and various other geospatial products and services for sharing throughout the state.

These datasets have been utilized by many state agencies and local governments to support economic development, property appraisal and management, emergency preparedness and response, utility management, crop delineation, asset management, planning and designing transportation infrastructure, environmental issues, permitting and code enforcement, improving spatial applications and services, etc.

Blueprint Columbus, which represents a substantial investment by the city, also benefits from these applications. According to DPU's "The Integrated Plan and 2015 Wet Weather Management Plan Update Report," the total capital cost of the Blueprint Columbus plan will be $1.7 billion. Over



This screenshot represents a QL0 lidar point cloud covering a portion of the Ohio State University's Main Campus in Columbus, Ohio.
Courtesy of Woolpert.

Building outlines, tree canopies and tree crowns, extracted from QL0 lidar, are represented in this screenshot. The Columbus (Ohio) Recreation and Parks Department, Urban Forestry Division, uses QL0 lidar data to produce canopy height and density models that estimate various measurements, such as a tree's crown and stem diameter or a forest's tree density and wood volume.
Courtesy of Woolpert.

20 years, it was projected that Blueprint will create an additional $2.8 billion in regional output, $977 million in earnings and create more than 700 jobs.

The program has four key pillars: lateral lining, roof water redirection, a sump pump program and green infrastructure. These pillars are being implemented in all Blueprint neighborhoods to keep rainwater out of the sanitary sewer system and protect the quality of water in the city's rivers and streams.

"The QL0 data allows us to create hydraulic model conduits using DEMs (digital elevation models) to appropriately represent curb gutters and tie those conduits into previous surveys, supporting flood mapping, open channel modeling, stormwater management, etc.," Edwards said. "Before a site can be built, we need to have all these calculations to size the stormwater runoff to determine how large the rainwater detention facility should be."

Edwards added that the department's Division of Sewerage and Drainage in particular wanted the data to be as accurate and extensive as possible.

"I suggested Woolpert could fly priority areas downtown that would cover 100 or so square miles," Edwards said. "But they had good reasons to fly the whole 680 square miles, because they had other ideas for using the data that could potentially reduce future topographical survey costs. When engineers start looking at this data, they see what they can do with it."

Woolpert used Leica TerrainMapper aerial lidar sensors to collect this data in March and April 2019. Flying back and forth in a pattern similar to mowing a lawn, the team collected the data required, checked the data for quality and completeness, and processed the data and delivered it to Columbus, enabling city planners and engineers to have shared access.

Through Blueprint Columbus, vacant lots are being converted into park-like locations to treat stormwater; this is being accomplished by planting trees and creating bioswales that slowly release any collected water into storm drains. In addition to the significant environmental benefit of providing improved water quality, the project also has increased property values in neighborhoods that have struggled with stormwater runoff problems. Specific project locations, searchable by address, and information such as green infrastructure locations, projected dates of construction, etc., are available on the city's website at columbus.gov/utilities/projects/blueprint/.

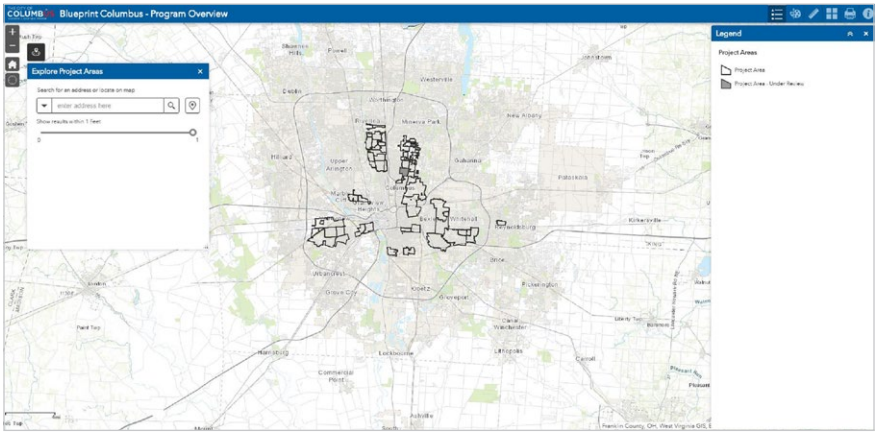
"There were immediate savings in cost and time by not sending surveyors out initially and later to recheck the site," Edwards said. "With this data, we don't need to duplicate efforts and collections not only within the city, but with other communities. In the past, we have shared the lidar data with other communities—Columbus extends across six counties—it's safe to say there would be interest in others getting this data, which will have applications for years to come."

Application branches out

The QL0 lidar data was procured to benefit Blueprint Columbus but, because the data is so accurate, Edwards said that many Columbus departments will likely come up with other possibilities for utilizing it in their projects. "Once people get hold of the data, they say, 'How did I ever function without it?'"

Some are already there. The city is in the middle of a large-scale project to install remotely-read water meters that use radio frequency identification (RFID) that will require installing repeater towers on the tops of buildings. Edwards said they will use point cloud data to determine the required height of buildings for installing the towers.

The city's Recreation and Parks Department also has found a use for the



The Columbus (Ohio) Department of Public Utilities' Blueprint Columbus initiative applies advanced technologies to direct rainwater out of the sanitary sewer system and into the storm sewer system. See columbus.maps.arcgis.com. Residents can search project locations by address and find information such as green infrastructure locations, projected dates of construction, etc., on the city's website at columbus.gov/utilities/projects/blueprint/.

data, according to GIS Analyst John E. Bowers, who works in the department's Urban Forestry Division. The division is responsible for having a detailed inventory of the city's public trees.

Bowers said that the division uses this data to produce canopy height and density models that estimate various measurements, such as a tree's crown and stem diameter or a forest's tree density and wood volume.

"Lidar allows these measurements and estimates for known public trees and identifies previously unknown public trees," he said. "Highly accurate data is better for these purposes, because it generates more precise measurements and estimates. When identifying individual trees from a lidar point cloud, having more returns decreases the chance that trees will be missed by the segmentation algorithm."

He continued that the division saves money using lidar because it generates an enormous amount of urban forest and tree data and eliminates the need to conduct inspections with a ground crew.

"Historically, our tree data was collected with a tape measure by an arborist or tree-trimmer on-site," Bowers said. "Inspection and maintenance intervals could be multiple years. Lidar measures the entire urban forest all at once every few years, so we have much more data that is recent and available for analysis."

Bowers said there are likely many other uses for lidar that have yet to be realized for the Parks and Recreation Department alone.

"Beyond Urban Forestry, the full scope of facilities and services for Parks and Recreation departments is vast," he said. "In addition to uses such as these that measure existing assets, lidar products could be used for multiple applications, including to guide where and how recreation areas could be developed."

Smart technologies, increasing applications

Utilizing lidar data in identifying existing assets and planning for engineering applications is just the beginning. This data is key to smart city initiatives that rely on the connection and communication of city functions—such as transportation, utilities and development—while reducing waste and costs.

Columbus, which won the U.S. Department of Transportation's Smart City Challenge in 2016, will be able to use this data to reinvent mobility and improve the quality of life for residents, drive growth, provide better access to jobs and opportunity, and foster sustainability.

Fang Cheng, engineer and project manager with the Division of Sewage and Drainage, said Columbus DPU engineers are currently considering other ways to use the data. She said these projects include comparing lidar-generated contours in ArcGIS with contours generated by traditional topographical surveys to reduce the traditional effort and costs on capital improvement plan projects. Other potential uses include 2D stormwater modeling for flood mapping, stormwater improvement studies and mapping areas prone to surface flooding and ponding or large-scale water quality, and open channel modeling to estimate pollution and explore river restoration.

Edwards appreciates how proactive Columbus is with geospatial technology, collecting lidar data every four to six years to monitor trends and changes in topography, infrastructure and the environment. He noted how these all affect impervious surface and therefore stormwater drainage and flooding, as well as transportation issues.

"The OSIP program has been great for the city of Columbus and has allowed us to work smarter with this technology," he said. "I think the addition of this QL0 data through Blueprint Columbus is going to be one of those building block datasets that is used on a number of projects throughout the city and region."

Brian Stevens is a vice president and geospatial program director with Woolpert, an international architectural, engineering and geospatial firm based in Dayton, Ohio. Stevens is a GIS professional and photogrammetrist with 20 years of experience in the geospatial industry. Working out of the firm's Columbus office, Stevens has led the Ohio Statewide Imagery Program (OSIP) since its inception in 2006. He can be reached at brian.stevens@woolpert.com.

NOT JUST FOR SURVEYING:

Lidar's Big Impact in Weather

How light detection and ranging technology is being used in relationship to weather

Photo courtesy Holle Meteorology Photography

We're all aware that lidar (light detection and ranging) data supports a myriad of surveying activities—from modeling and mapping to emergency response and vulnerability analysis—but not as many people know that lidar technology allows us to understand weather in a way that hasn't been done before.

Much like in surveying and mapping applications, lidar is a remote sensing method that uses pulsed laser light. Rather than being pointed at a targeted area on the ground to measure a range, in weather applications, short pulses of laser light are shot into the atmosphere to measure atmospheric constituents, such as aerosols, pollutants and other particles—and their dynamics. When light is reflected off of these components, it's backscattered into an opto-electronic detector, and the return pulses reveal a profile of these atmospheric elements and the corresponding distance between those elements and the lidar device. Analyzing this information yields information about the variable distances and distribution of molecules and particles in the atmosphere.

Necessary for myriad applications, from climate modeling and land surveying to weather forecasting and more, the data lidar systems reveal is incredibly useful across the meteorology, aviation and wind energy sectors.

Meteorology

Weather can be difficult to predict. But weather forecasting is extremely

BY FLORIAN REBEYRAT

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Leosphere Windcube Scanning Lidar measures wind for development and operations applications.
Photo courtesy NOAA

important for all economic activities impacted by atmospheric conditions and pollution at a certain place and time, including blistering heat, fog, haze, smog, heavy wind, rain, snow and other critical events.

Most natural disasters stem from severe weather phenomena, including thunderstorms, hurricanes, hailstorms, tornadoes, heavy precipitation, flooding and damaging winds. Worst of all, these disasters often lead to human casualties and property damage. Detecting and forecasting hazardous meteorological events allows decision-makers to warn citizens and execute timely emergency response and rescue operations. From maritime ports and airports to industrial sites and leisure activities, monitoring and forecasting meteorological threats is incredibly important.

Where weather is concerned, the next generation of high-resolution weather prediction models will require a very high level of spatial and temporal continuity that only a combination of technologies can offer. Existing observation networks need to be complemented with denser and more local networks for better understanding, monitoring and forecasting of severe weather.

Used to investigate and analyze atmospheric properties from the ground up to the limits of the lower atmosphere, lidar sensors fill the gap between the ground and what satellites can observe from space. Satellites struggle to provide data below clouds and close to the ground. Met agencies need an accurate complement to satellite data and numerical weather forecasting models to identify, locate, characterize and quantify atmospheric constituents and dynamics from near-ground levels all the way to the top of the troposphere. Lidar helps with visualizing what's "invisible," aiding atmospheric researchers and climatologists trying to model the complexity with a better understanding of our atmosphere.

Measuring aerosols, temperature, pressure and humidity using networks of remote sensors feeds climate models and databases with continuous profiles of the optical properties of the aerosols and meteorological constituents in the atmosphere. Using mathematical models of the atmosphere and oceans, advances in numerical weather prediction (NWP) represent a quiet revolution because they have resulted from a steady accumulation of scientific knowledge and technological advances over many years. A number of forecast models use weather observations relayed from lidar sensors as inputs. These lidar networks help met agencies monitor the meteorological impact, greatly improving short- and long-term weather forecasts. Already being used in New York state to improve the detection and prediction of severe weather events, 17 lidar units have been integrated into enhanced weather stations dispersed throughout the state to provide real-time observations.

Aerosols accelerate the melting of glaciers by darkening their surface, they damage electrical and transport infrastructure, and when combined with local pollution, they also worsen air quality. Poor air quality is the most serious environmental health issue globally and the primary driving force for ambient air quality monitoring. When it comes to air quality, lidar has two applications: monitoring of emissions and forecasting of air quality. Mapping the distribution of aerosols in complex urban environments allows air quality operating agencies to tackle exposure challenges, identify source hotspots or manage the positioning of

air quality stations. The ultimate goal of doppler lidar technology is not only to describe and understand the physical and chemical processes, but to drive urban development strategies and better forecast air quality and meteorology at large urban sites as well.

From an observational perspective, meteorological data has historically been measured using radiosondes twice a day, and that remains the most common practice in obtaining current weather data. The main advantage of remote sensing lidar instruments to complement radiosondes is the potential offered by nearly continuous monitoring. Meteorological forecasting and nowcasting mainly improves with more frequent observation.

It's crucial that meteorological agencies continuously monitor all meteorological and atmospheric parameters, including wind, turbulence, clouds and aerosols, so they can contribute to efficient and effective crisis management assistance by public authorities and private companies. When it comes to the high-resolution data lidar instruments reveal, that information can help predict local severe weather and storm formation as well as generally improving weather forecasts, ultimately saving time and lives.

Scanning Lidar measuring wake turbulence at an airport..
Courtesy of Leosphere

Aviation

As far as the aviation industry is concerned, lidar has two fields of application: safety and efficiency. Airports use lidar technology to gather real-time and highly accurate wind and aerosol measurements adapted to the airport environment, providing critical information that helps ensure safe takeoffs and landings and improves overall air traffic management (ATM) efficiency.

One of the major causes of accidents during takeoffs and landings, inclement weather is an unfortunate and costly reality for many airport hubs around the world. The primary concerns for pilots and air traffic controllers are weather and wind, but lidar solutions at airports are helping to mitigate wind-related hazards.

The number one threat in aviation weather, wind shear can be described as a sudden change in wind speed and/or direction that causes a plane to deviate from its intended flight path. The unpredictability of wind shear is responsible for the disruption of air traffic, significantly impacting airport operations. Wind shear involving changes in headwind or tailwind of 15 knots or more have been determined to be a serious danger that could adversely affect an aircraft's lift and air traffic operations, per the International Civil Aviation Organization (ICAO). To that point, wind shear phenomena have caused more than 1,500 deaths in aviation since 1943.

Statistically the most dangerous flight phases, the final approach and initial take-off paths require a proper measurement and alerting system to determine the *right* moment to take off or if pilots need to avoid or be careful of specific events. Lidar technology is one of the best technologies for wind shear monitoring due to its ability to detect clear air wind shear events, which are invisible to pilots and air traffic controllers, over a 10-kilometer approach. Updated every minute, wind shear alert data from the lidar sensors can be embedded in the

Windcube Scanning Lidar
Photo courtesy NEA

automatic weather observing system (AWOS) and displayed in the AWOS interface like any other meteorological information, automatically generating alerts for air traffic controllers.

Additionally, lidar can measure any wind or turbulence, improving the wind awareness around the airport. This information helps meteorological office forecasts to get a better understanding of wind conditions around airport and make further decisions surrounding safety.

As far as efficiency, lidar also measures wake turbulence generated by the wings of aircrafts. A major concern in air traffic management (ATM), measuring the wake turbulence allows for air traffic growth through improvement of runway throughput. Today, air traffic is regulated with minimum distance separations, which are sometimes considered as overconservative. A more comprehensive understanding of the wake turbulence characteristics enables ATM to apply new distance separations while removing the risks related to this phenomenon.

The only technology able to characterize wake turbulence in application today is wind lidar. In specific configurations, lidar sensors acquire wind data, and unique software computes the characteristics of the vortex turbulence, generating a database of the behavior of wake turbulence at a given airport. To safely reduce the minimum separation between a given pair of aircraft, whether on departure or on final approach, both the wake vortex generated by the leader and the following aircraft's resistance to it have to be taken into consideration. Based on this information, ATM controllers can safely apply reduced distance between planes, ultimately improving runway throughput and airport capacity.

Wind Energy

Whether developing or operating a wind project, it's important to understand what the wind is doing—and lidar helps do precisely that. Lidar measures the full wind regime and characteristics of the wind flow, including wind speed, wind direction and turbulence all the way up to 200-plus meters.

When it comes to producing wind energy, bigger turbines and more efficient wind farms are the name of the game. In fact, based on Electric Power Research Institute (EPRI) data, a 1% annual production increase at a typical wind farm with 100 two-megawatt turbines can increase revenue by up to $500,000 per year.

However, a significant amount of time and effort goes into developing a wind farm before the first turbine begins producing energy. Prospectors measure the wind's behavior at a given location for at least one year before a development plan is approved—and accurate data is the primary variable in their bankable wind resource

assessment. Consequently, inaccurate wind measurement can result in less favorable financing conditions, an incorrect investment decision or the wrong type of machinery being selected, which can lead to underperformance or failures.

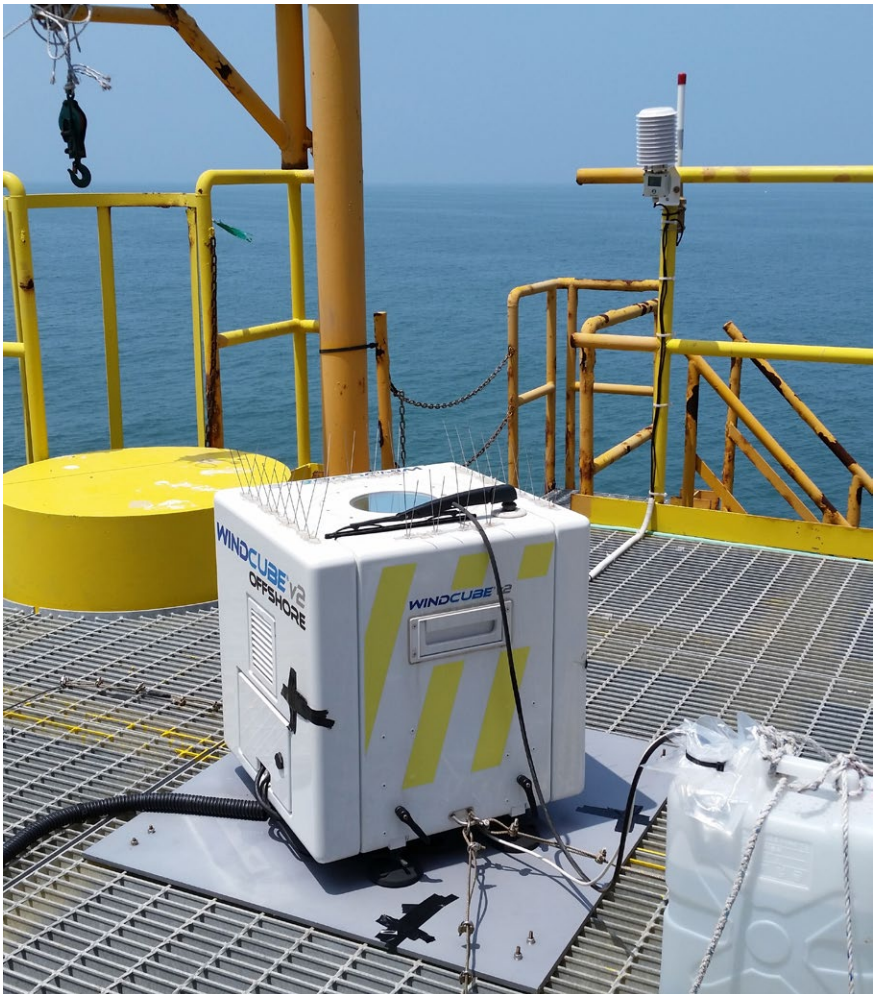
Meteorological evaluation towers, often referred to as met towers, have traditionally been the primary technology to conduct wind measurement, but as turbine height grows beyond 150 meters tall, met towers are unable to deliver data at such height with reasonable costs and safety conditions. Lidar allows for accurate and more expansive measurements of the full wind profile in the prospecting phase, helping determine the wind turbines to be selected and how much wind energy a future wind farm would produce.

Permitting and installing met towers takes a significant amount of time before wind prospecting even begins. But developers that use lidar sensing not only shave weeks or months off their development phase, they are also empowered with the benefit of mobility. If they need to move the sensor for a more impactful measurement, they can do that safely in a matter of hours. There's no permitting required or tower to build.

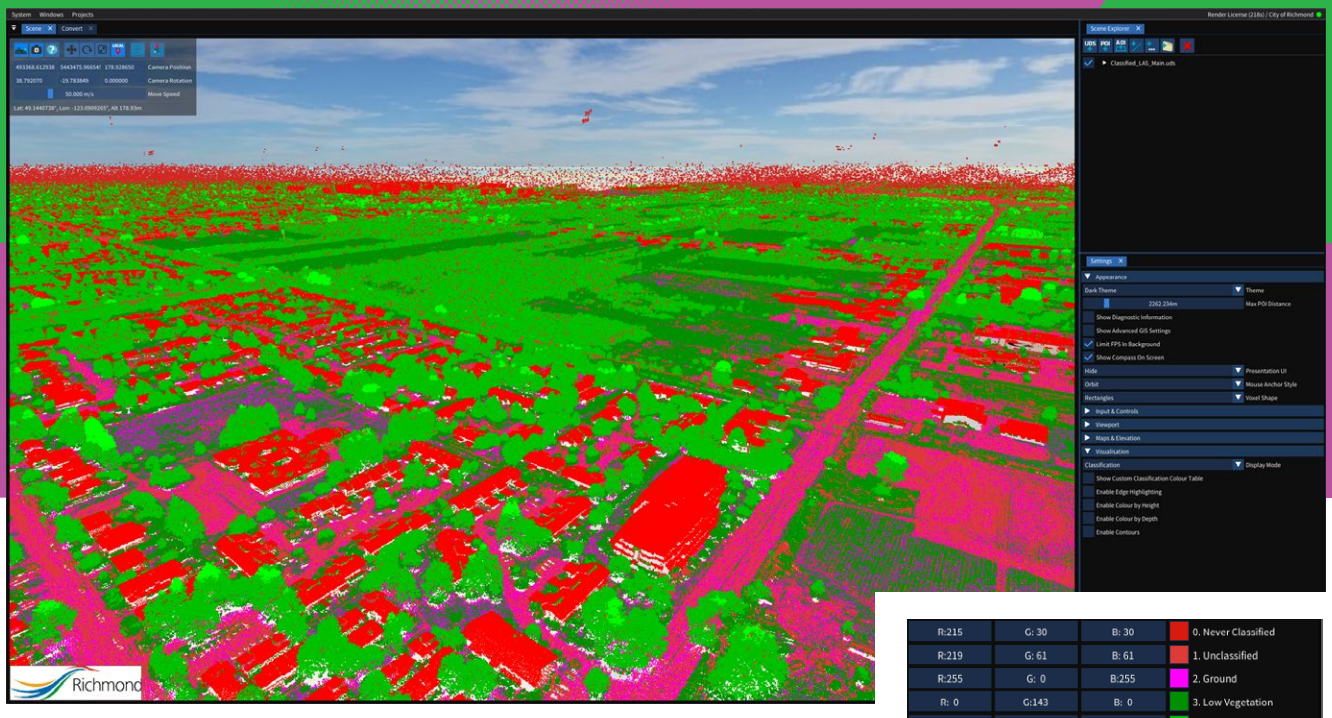
Additionally, lidar technology can be mounted on the wind turbine's nacelle itself to scan in front of the turbine, measuring the wind that will hit the rotor. That way, wind farm owners can use it as a diagnosis tool to verify and optimize their assets, securing their revenue. It can also be installed permanently as a turbine component to improve the turbine reaction to the ever-changing wind conditions, leading to an increase in energy production—through better alignment to the wind—and turbine lifespan—by limiting the stress on key components such as gearbox, rotor or tower.

While the first commercial lidar products for these meteorological, aviation- and wind energy-related applications didn't reach the market until the early 2000s, lidar technology matured very quickly. As lidar technology continues advancing, the revolutionary sensing technology will only find additional applications as it permeates new industries and continues to provide more accurate and more robust data. Lidar technology has already allowed us to understand weather in a way that hasn't been done before, benefitting myriad industries—what's next for the future of lidar?

With extensive experience in the wind industry in Europe, Asia and North America, **Florian Rebeyrat** has a strong a track record of bringing cutting-edge technology products to market. Florian leads the business segment and product management function for the wind energy product lines of Leosphere, a Vaisala company. Connect with Florian on LinkedIn.



Windcube lidar for offshore wind measurement.
Photo courtesy Leosphere



The City of Richmond, Vancouver as a 3D dataset in Euclideon Vault software, colored by classification.

R:215	G: 30	B: 30	0. Never Classified
R:219	G: 61	B: 61	1. Unclassified
R:255	G: 0	B:255	2. Ground
R: 0	G:143	B: 0	3. Low Vegetation
R: 0	G:191	B: 0	4. Medium Vegetation
R: 0	G:255	B: 0	5. High Vegetation
R:255	G: 0	B: 0	6. Building
R:207	G: 44	B: 44	7. Low Point / Noise
R:255	G:255	B: 0	8. Key Point / Reserved
R: 0	G: 0	B:255	9. Water
R: 0	G:224	B:224	10. Rail
R:224	G: 0	B:224	11. Road Surface
R: 66	G:249	B: 63	12. Reserved
R:189	G:158	R: 3	13. Wire Guard / Shield
R: 89	G:214	B:125	14. Wire Conductor / Phase
R:157	G:163	B:120	15. Transmission Tower
R:123	G: 50	R: 42	16. Wire Structure Connect
R: 36	G:120	B: 60	17. Bridge Deck
R: 87	G: 38	B: 65	18. High Noise

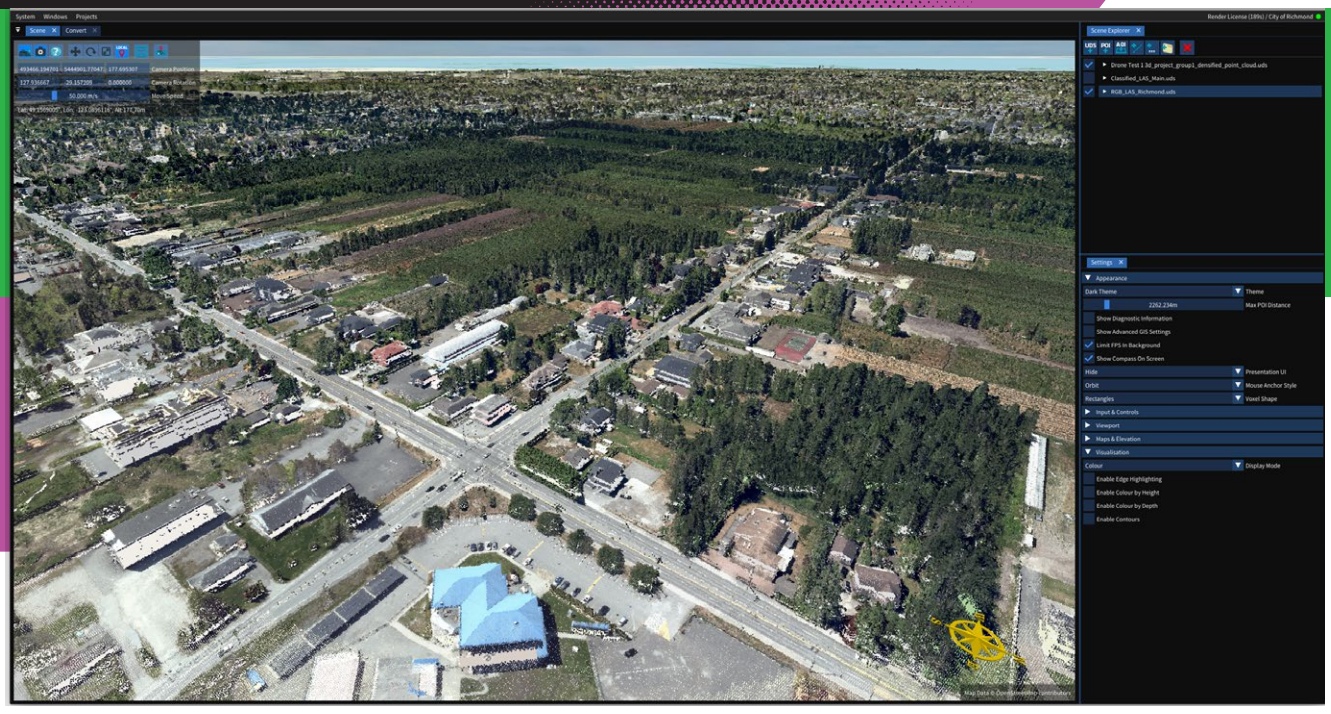
Classification Color Table

Crunching the Numbers

New software solution lets municipality handle massive volumes of lidar data, improving dike inspection process and more.

BY LARRY TROJAK

While hailed as one of the great achievements in modern survey and measurement technology, lidar has long been hampered by the very product it creates. Huge data sets, representing information gathered, have resulted in extremely long periods of post-processing and an end-product which, while impressive to view and manipulate in small sections, has often been too large to be viewed in its entirety without expensive workstations. This was the issue facing the City of Richmond, British Columbia, Canada, as it worked to move its GIS effort—which included monitoring of the city's 47 km long series of dikes—forward. Faced with a staggering amount of data and only a limited capability for viewing it, the city turned to an Australian software development firm whose claims for handling massive data sets seemed improbable at best—but ultimately proved even undersold. Today, thanks to that solution, Richmond is able to view photorealistic 3D point cloud renderings of the *entire city*; can "fly" its way through those images from a standard, off-the-shelf laptop; and sees applicability in a range of areas. The developer calls its solution "VAULT," the city calls it a game changer.



A high resolution color lidar scan of the City exceeding 1TB in file size, which can be viewed in under one second using Euclideon Vault."

Bayou Nord

Like New Orleans, Louisiana, to the south, Richmond is a river delta city located on a flood plain. Situated just 1 m above sea level, it is encircled by dikes to keep the waters of the Fraser River at bay during times of flooding and as the effects of climate change become more prevalent. According to Michael Bleidistel, the City's systems analyst (GIS), their GIS effort has been in place for some time now but has taken some serious turns of late.

"For decades now, we have maintained a solid GIS effort, primarily for asset management," he said. "Like any city, we are constantly renewing and upgrading our infrastructure to ensure that the quality of life for Richmond residents is made better. To that end, the engineering department gets 2D drawings from our survey people and turns those into actual features on the ground. Areas such as sewer and water, drainage and so on benefit from that."

The importance of Richmond's GIS effort is made even clearer when one considers its geographic situation. The island on which the city sits, Lulu Island, is surrounded by a series of dikes which must be regularly monitored for condition and wear. Unfortunately, doing so had previously consisted of dealing with mostly 2D data—photographs taken from boats, for example.

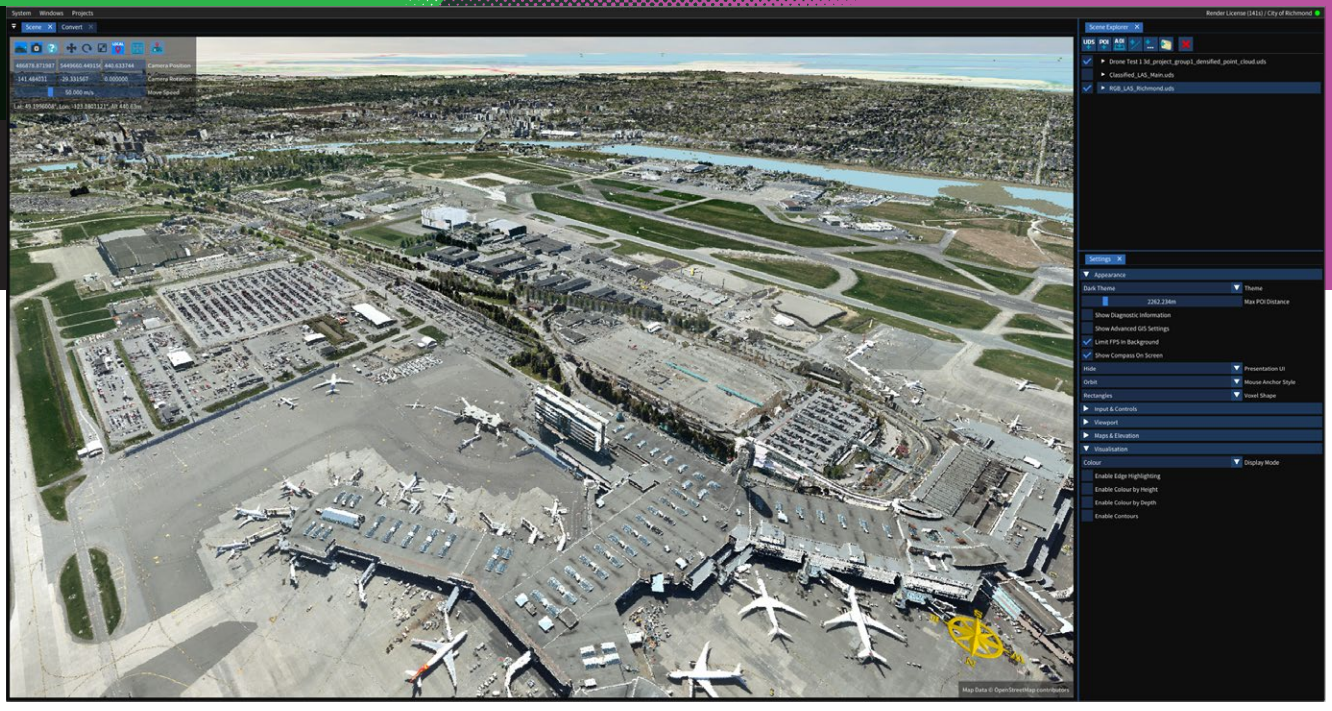
"For the last few years, however, geospatial providers such as McElhanney and EagleEye have been flying the metro Vancouver area and providing us with aerial photos or lidar data of our region," said Bleidistel. "While the photogrammetric data was great to have, it was barely useable because the data sets they created were so large. And while we could cut the lidar data into smaller sections to allow conventional software such as ArcScene or ArcGIS Pro to load it, doing so meant we were missing the 'big' picture. We needed to change that."

A Different Approach

Bleidistel said that, for a couple of years, he had been following the projects on which Euclideon had been working. While some of it was not immediately applicable to the needs of GIS people like himself, he saw where things were heading and was definitely intrigued.

"Much of Euclideon's efforts were related to improving the look of video gaming backgrounds and environments through the use of what the company calls Unlimited Detail Technology," he said. "However, about a year ago, they announced that they'd applied the benefits of that technology to GIS-related 3D modeling. Since we were getting all these large-volume data sets from the geospatial providers and were largely unable to work with them, that definitely got my attention. So, I reached out to them and arranged to get a license."

At the heart of Euclideon's VAULT solution is a 3D search algorithm that can render unlimited quantities of point-cloud data in real-time. Because this algorithm efficiently grabs only one point for every screen pixel, it can display models of previously unimaginable sizes—at interactive



Euclideon Vault allows live IoT data feeds of the Richmond airport to be projected onto their geo-located 3D model.

frame-rates—without the need for a powerful CPU or graphics card. A spokesman for Euclideon explains it :

"Consider Google which, basically speaking, is an extremely powerful 1D search algorithm used to look for words on the internet," he said. "When someone enters a phrase, it looks as though Google has read the entire conglomeration of all human knowledge in less than a second, and then offers a list of where to find such things. That is the power of search algorithms. Our technology employs a 3D search algorithm that looks for little atoms, and only wants one of them for each pixel on the screen."

Decidedly Denser Data

The approach being taken by Euclideon appealed to Bleidistel not simply because it was able to efficiently tackle mega-files, but also because he knew that, with the processing bottleneck removed, the quality of data they could handle would be vastly improved.

"The photogrammetric data we were getting from the aerial crews was collected from an aircraft flying at 250-300 mph," he said. "Given that, the closest distance between points it could gather was about 0.75 m and it still created a 48 GB file. Knowing what was possible using VAULT, we employed a drone to fly the dikes and reduced that point distance to a much denser rate—about 1.2 cm between pixels. The detail we were able to get on that project by overlaying the tight data on to the course info was so great that the City is considering either initiating a drone program of its own or, at the least, contracting out to someone to do it."

It is worth reiterating that being able to monitor the dike system in this manner and to this degree is a huge asset for the City of Richmond. Just as the City relies upon the structures' integrity and performance, so too does Vancouver International Airport, the second busiest in all of Canada, which is located on Sea Island adjacent to Richmond.

"Overlaying data collected by drones or third-party providers allows us to do visual inspections 'on the fly' and at regular intervals," said Bleidistel. "This, in turn, will allow us to better anticipate upcoming repairs by foreseeing issues from those visual inspections. Compare that to examining thousands of photos taken from boats and it's easy to see why we are so excited."

Break Out Success

An additional benefit VAULT has provided Bleidistel's GIS function is

A small, lower resolution point cloud, typical of what the City of Richmond previously accepted, before they adopted Euclideon Vault.

somewhat ironic: the ability to break large files down into smaller, separate components when it's called for. Although being able to easily handle a 1 TB file is a nice luxury to have—and as recently as a year ago seemed like only a pipe dream—not everyone wants or needs that volume of data.

"VAULT makes it easy to pull out an individual section of a large file," he said. "I often have consultants contacting me for the lidar data from a specific area and, rather than just handing them a huge data set, I use the Euclideon's Massive Data Manager (MDM) to pull out the area they need and export it as a lidar set. They prefer that, and this solution makes it fast and easy to do so."

As He Sees It

If Bleidistel seems to be something of a cheerleader for the new solution (he confesses to having repeatedly touted it to his peers at conferences and meetings), perhaps that's because he's had to both rely on the cumbersome approach (manually-shot 2D photographs) and deal with the massive data sets mentioned above. Though his initial involvement was just a pilot program for the City, he is confident that they will not be moving forward without the VAULT solution

"Having a digital, geospatially accurate representation of an object or area in front of you, rather than seeing it in 2D is a huge paradigm change," he said. "Without VAULT, and before that, MDM, no-one ever believed that you could view that amount of data in one app, let alone have it streaming from a server!"

He added that City officials had previously used one of the well-known VR headsets, viewed a three- or four-block section of the city and discovered that it not only taxed the system, but it was very easy to get lost.

"By comparison, with VAULT, the fact that we were able to 'fly' the entire island, look around and see landmarks and other reference points, made them gasp. I always believe in spreading the word when I find something that is truly game-changing—this is definitely such a case."

Larry Trojak is is president and owner of Trojak Communications, a Minnesota-based marketing content firm. He has written extensively for clients in the construction, recycling, demolition, geopositioning, and wastewater treatment industries.

Regular monitoring by laser scanning from drones creates accurate—but massive—3D models.

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Levee Assessment After Hurricane Harvey Utilizing UAV-Lidar

Texas geospatial service provider provides critical data fast

BY SCOTT MCGOWAN

The aftermath of Harvey

Harvey began as a small, slow moving tropical storm in mid-August 2017. It was categorized as a tropical wave as it grew in strength off Western Africa. It brought brief storm conditions to the Windward Islands a few days later then diminished back to tropical wave status. As the tropical wave moved east, it fed off the increased humidity produced from the warm sea conditions and Tropical Depression Harvey progressed into Hurricane Harvey by the third week of August 2017. Continually feeding off the warm ocean conditions, Hurricane Harvey reached Category 1 by August 24th and Category 4 by August 25th. By this time it was heading directly toward the Texas coastline just south of Houston. Hurricane Harvey made landfall at Rockport, Texas late on August 25th as a Category 4 Hurricane with sustained winds of 130 mph and torrential rains. Stalling on the coast for most of August 26th, it degraded to Tropical Storm Harvey from a wind perspective, but as it moved north into the Greater Houston area, it brought unforeseen torrential rains that caused catastrophic flooding the likes of which had never been seen in Texas. 500-year flood zones were exceeded and two flood control reservoirs in the Houston area were breached, flooding their respective communities. Levees throughout greater Houston were brimming and the collective breath of all Houstonians was held in unison, hoping that the rain would stop and the levees would hold.

Hurricane Harvey would become the first major hurricane to strike southeast Texas in over four decades. In its wake would follow over 125 billion dollars in

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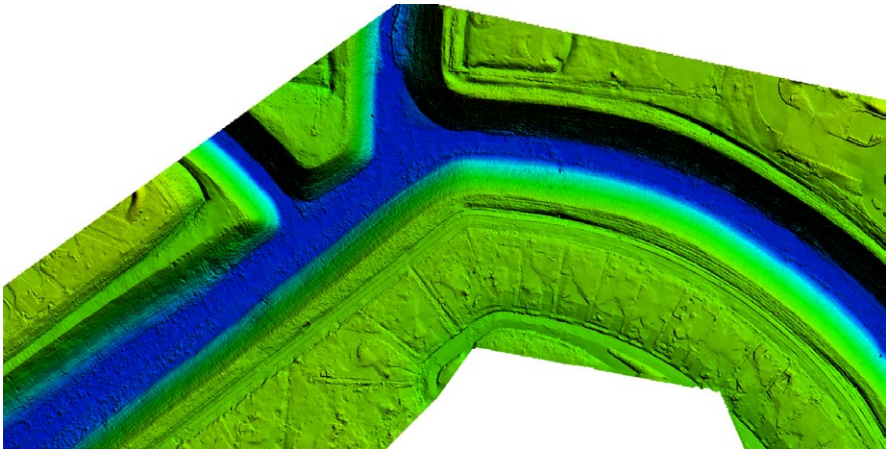
damage and it would rank second only to Katrina as the most costly hurricane in US history. Hurricane Harvey would be responsible for 135,000 destroyed homes, 13 million residents adversely effected and close to a million automobiles, trucks and other vehicles destroyed. The death toll stands at 88.

The unifying slogan of "Houston Strong" would be the mantra of the survivors of this disaster and a nascent, somewhat reviled industry would finally gain acceptance as a mainstream provider of life-saving intelligence, disaster response and quick, accurate damage assessment. The UAV had finally made it into the mainstream conscience of America and would continue to provide a technological wave of valuable data to post-Harvey Texas and then, within weeks, to Florida and Puerto Rico.

The situation

As the city of Houston and the greater Houston area began to recover from the devastation and flooding damage in Harvey's wake, it became essential to begin the postmortem on the levee system and ancillary flood controls. Did the levees perform to their projected capacity? How much degradation to the levees had happened as a result of the flood waters' effect on their substrate? How could such a large, logistically challenging and data-intensive survey be done affordably, accurately and efficiently?

Levee systems are constructed and maintained to restrict the movement of flood waters from reaching communities and structures in the proximity of areas known to be flood-prone. In the case of greater Houston, the levee system is used to control the flooding of the Brazos River in Fort Bend County, Texas. This levee system was initially constructed in 1913[1], enabling the surrounding area to be developed with numerous homes, shopping centers, sports facilities and education buildings. For example, the rapid expansion in the later 20th and early 21st centuries of the city of Sugarland, Texas has been directly related to the expansion of levees and increased flood control projects. This area has been a booming financial and residential district with a bright future, but heavily reliant on the integrity of its levee system.



Example of digital elevation model of levee area, color-coded by elevation.

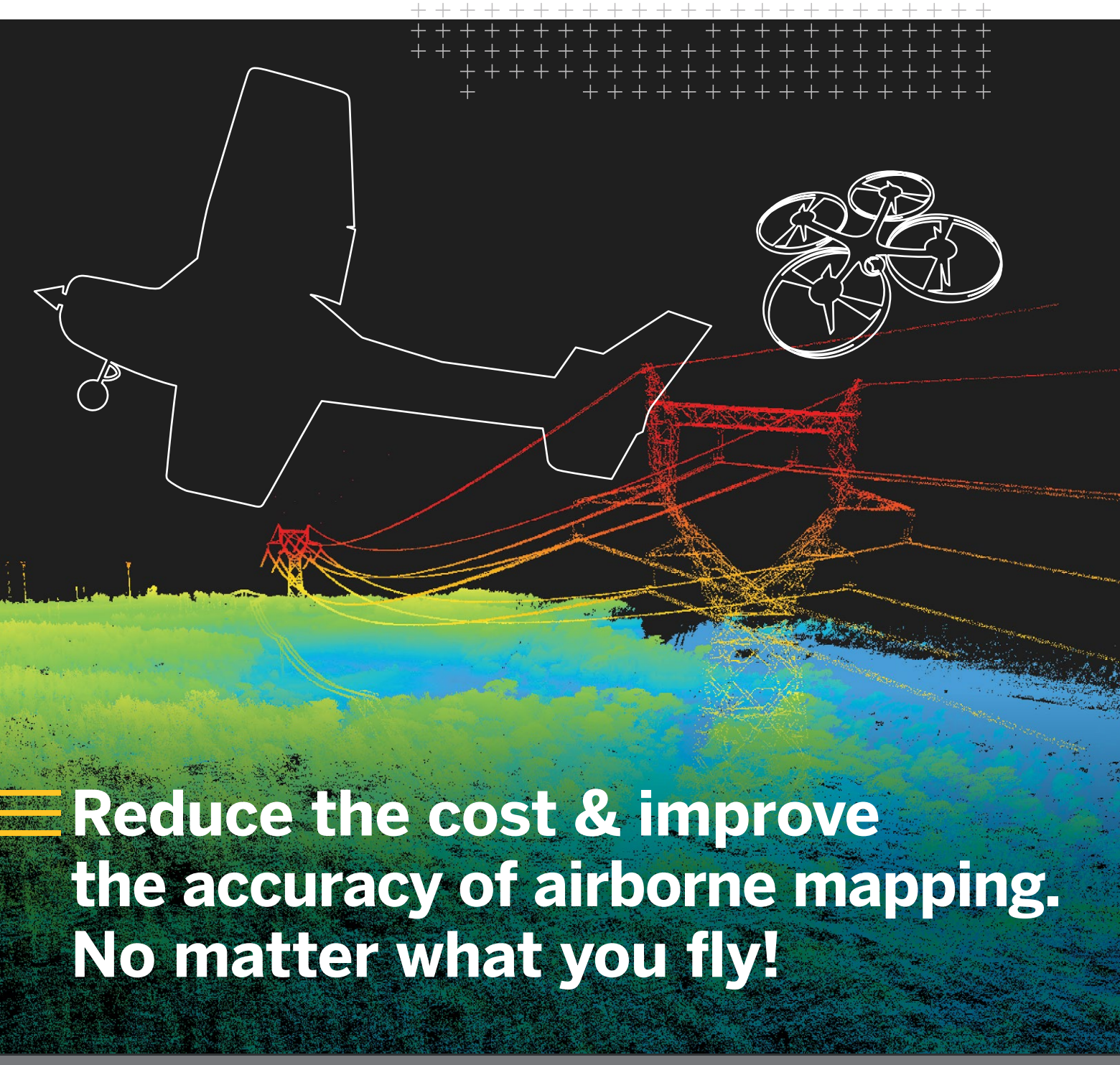
With approximately 99 miles of levees in Fort Bend County[2], the various Levee Improvement Districts (LIDs) and Municipal Utility Districts (MUDs) are responsible for the construction, management and maintenance of their respective levee systems. Over time, the levees are subjected to periods of intense heat and sometimes considerable drought conditions like those experienced in 2012. These conditions make the clay-based substrate compress and dry out, reducing the overall height and volume of the levee. Once the droughts subside and the levee is again exposed to periods of copious rainfall, this substrate swells as the water is absorbed. Unfortunately, this re-hydration of the substrate does not replace the full volume of what was lost during the drying and compression period, so the levee is reduced from its required mass, height and slope angle. This becomes critical in the management of the levee, because these three key elements—height, mass and slope angle—are essential to its viability as a barrier.

Traditionally, surveys of the levees to assess the above criteria were performed by professional surveying companies utilizing RTK-GNSS sampling in grids with spacings of 100-150 feet. This data was used to calculate the height, mass and slope angle of the levees in question. Such sampling surveys have been the standard of the industry for decades and, although very accurate, are very time-consuming and expensive.

The solution

Precision Aerial Compliance Solutions, a Texas-based UAV services company, was contacted in late 2017 by a Houston area township to perform a UAV-lidar survey of its drainage system. The purpose was to assist in the modeling of the system and determine how it had been affected by the large volume

1 https://www.sugarlandtx.gov/1695/History-of-Fort-Bend-County.
2 http://www.fbclid2.com/about/.



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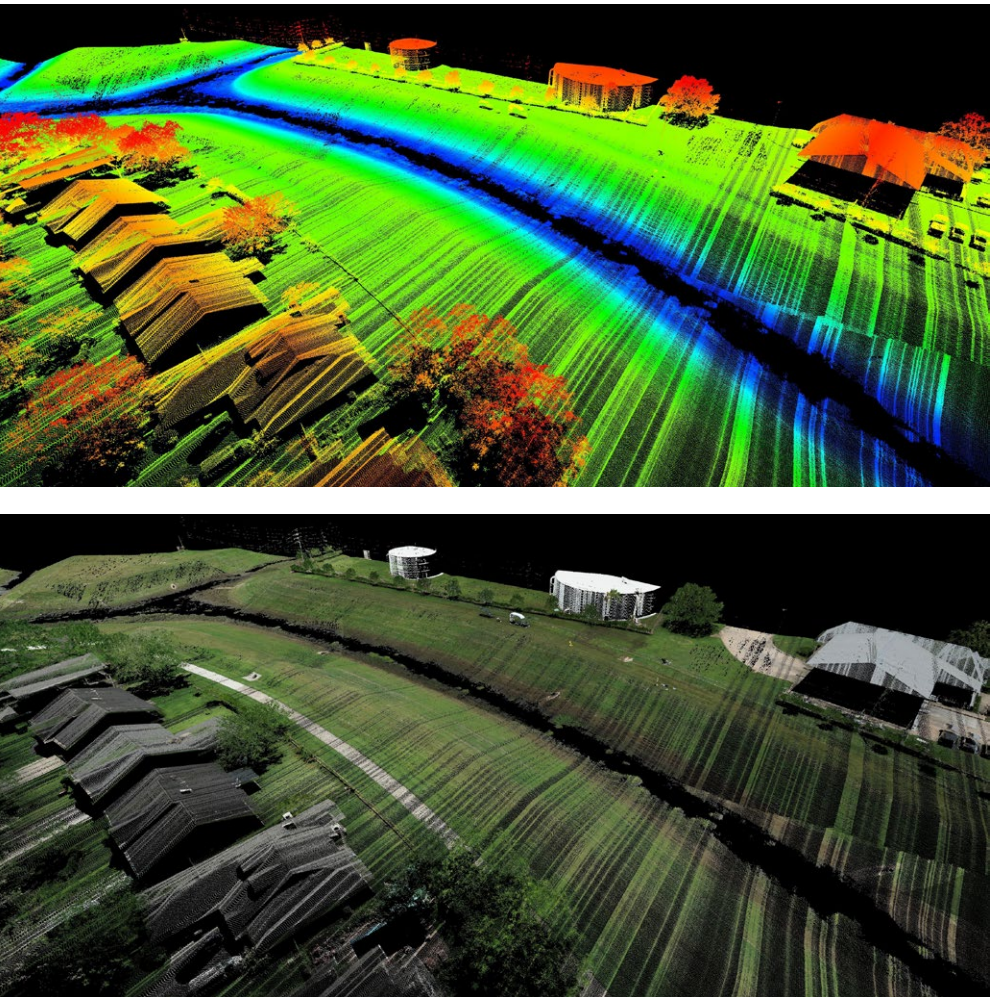

Typical deliverables from Precision Aerial: oblique view of lidar point cloud, color-coded by elevation (top) and by RGB values from imagery (bottom).

of flood water that flowed through the town during Harvey and pinpoint the major damage areas from the hurricane. Precision Aerial was able to complete the task, which would have required months of traditional survey, in little over a week and proved that UAV-lidar provided a viable means of delivering critical, accurate data from difficult-to-reach areas in a short period of time.

In 2019 Precision Aerial was asked to perform three levee surveys utilizing its UAV-lidar systems as a result of the proven accuracy and efficacy of its previous work on post-Harvey projects. The goal was to provide accurate and far more granular data than had previously been provided by traditional methods. Precision Aerial chose to utilize its recently purchased RANGER from Phoenix LiDAR Systems, comprising a DJI Matrice 600 Pro with RTK GNSS, RIEGL VUX-1 lidar sensor and Sony A6000 36.4 megapixel camera. The Phoenix RANGER is capable of 500,000 laser pulses per second with up to seven returns and a near-infrared laser. The calibrated Sony A6000 can acquire images every 1.8-2.0 seconds, resulting in a rectified orthomosaic that can be accurately overlaid on the lidar data to colorize the lidar data points. The end result is a dense, accurate deliverable that resembles a video, but is a three-dimensional fly-through of the data environment as seen in the example to the left.

To achieve this accuracy when combining the two different forms of data requires both the sensor and the camera to be precisely bore-sighted for alignment as close to perfect as possible. It should be noted that the swath width of the lidar sensor on the ground is considerably greater than that of the imagery from the Sony. Therefore the pilot and flight planner must adjust the flight plan grid accordingly, so that the photos will be compatible with the lidar data and overlay perfectly. See an example overleaf of correct flight plan spacing.

The first project Precision Aerial flew was for a Fort Bend County LID that was responsible for approximately 11 miles of levee. Precision Aerial's alpha team flew a precise four-leg linear grid pattern parallel to the levee in 1.5 mile segments. The full extent of the levee and corresponding areas of interest were completed in one work-day with the Phoenix RANGER. A GNSS base station was used in conjunction with an onboard RTK system to provide real-time corrections for the grid pattern flown by the Matrice 600. In concert with the Trimble R8 base station, the Phoenix RANGER becomes a flying rover.

Precision Aerial was contracted later in the summer of 2019 to supply lidar data and imagery for two areas that

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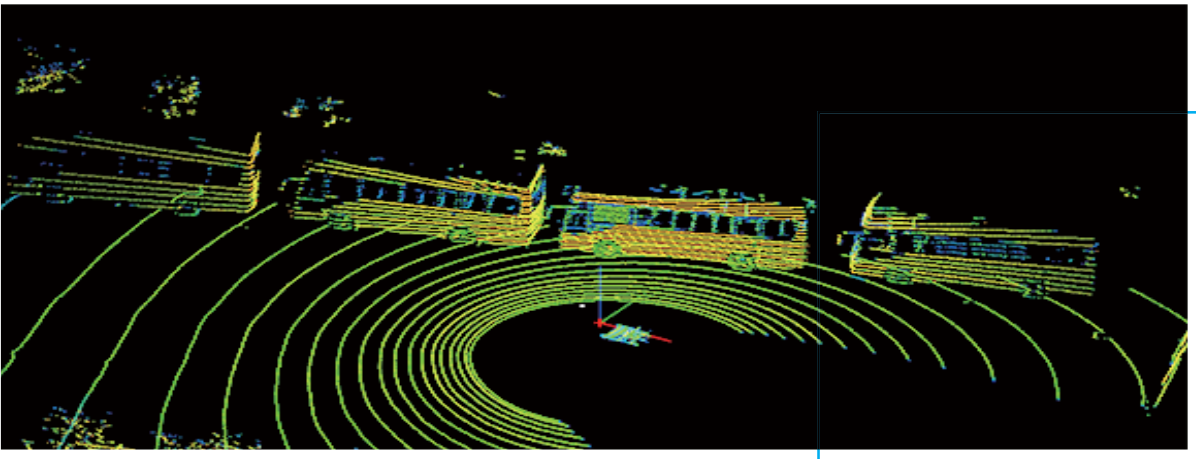

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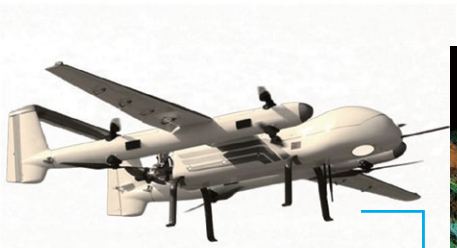
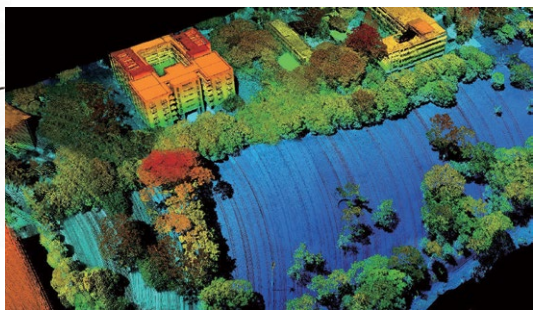
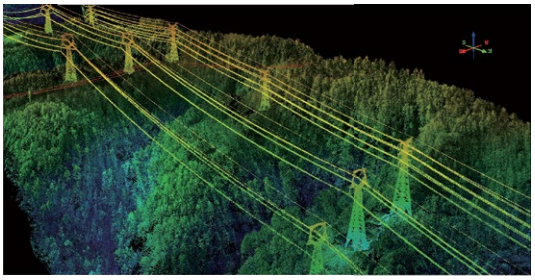


Clouds





Survey grade UAV LiDAR

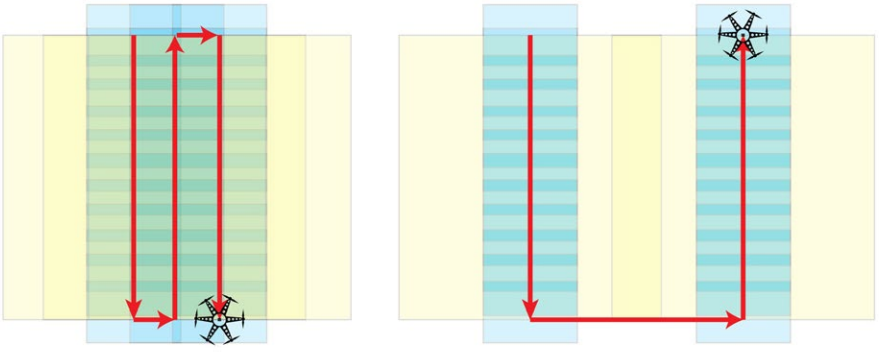
Precision Aerial's RANGER system in operation. This system, based on DJI M600 UAV and RIEGL lidar sensor, was supplied by Phoenix LiDAR Systems, Los Angeles, CA.

contained levees and drainage ditches, and required a 300-foot additional swath beyond the borders of these assets. These two areas of interest posed a more intricate challenge: although separate data sets were required, the areas were aligned contiguously and had their levee and drainage systems intertwined. A scout mission was flown to acquire aerial imagery of the areas. After evaluating this data, Precision Aerial chose to utilize both alpha and bravo teams to fly the respective overlapping areas. It was decided to deploy the two Phoenix MiniRANGER systems so that the data would be easier to rectify during post-production. The MiniRANGERs utilized the DJI Matrice 600 multirotor as the sensor's flight platform. Imagery for photogrammetry was provided by Precision Aerial's two Eclipse RTK fixed-wing UAVs that utilize the Sony RX100 24-megapixel camera. Precision Aerial flew these two projects in very close proximity to a local airport, where a portion of the mission was in "zero airspace". Fortunately, Precision Aerial's close relationship and history with the tower enabled it to fly the missions at 200´ AGL. Constant contact was maintained with the tower before, during and after the mission.

Precision Aerial was able to complete both lidar missions and both imaging missions in one day. This encompassed over 20 miles of levee and 7 miles of drainage ditch. The data collected was exactly what the clients needed and will help them to plan for future flood events.

While UAV systems flying advanced lidar sensors aren't a complete replacement for traditional survey, and check shots by a PLS are still required, they have ushered in a new age of rapid and accurate data collection never before available. UAV-lidar provides considerable acceleration to the survey workflow and makes surveys like the above possible in a fraction of the time and generally at a considerable cost savings. With this option available to the many LIDs and MUDs in Texas and elsewhere, future planners and commissioners tasked with the responsibility of mitigating and responding to the effects of flooding, hurricanes and other natural disasters will now have a new, powerful and disruptive tool at their disposal.

Scott McGowan is president and CEO of Precision Aerial Compliance Solutions, LLC (precisionaerial.co). The company was founded by Scott McGowan and Jason Nicholas in 2015. Precision Aerial was an original FAA 333 exemption holder and one of the first UAV companies to be credentialed by the National UAS Credentialing Program. Precision Aerial is based in Conroe, Texas and operates throughout the USA and abroad.



Phoenix Flight Planner enables clients to build flight plans that optimize data collection based on factors such as laser strength, vegetation, terrain, and more. The resulting KMZ can be uploaded for autonomous UAV flight, further simplifying the lidar workflow.

Graham, *continued from page 48*

or vegetation). I've set transparency on the GeoTIFF layer to 50% so you can see the underlying point cloud data. It looks as if we have excellent density to support a 1 m gridded product since there are only five cells indicating insufficient density.

However, the product we desire to make is a 1-meter gridded elevation model of the *ground.* Thus I should be doing the analysis against points that actually are on the ground! **Figure 3** shows the density test run on the point cloud data using only points classified as ground. As you can see, major areas of this data set would not support creating a high resolution (1 meter post spacing, in this example) DEM.

So the point (pun intended) here is that we should always analyze point cloud data in the context of the downstream products that we need. For a ground DEM, we should be examining the characteristics of the points that will be used to generate the ground. As seen in this example, the fact that I have a nice dense point cloud with full coverage of single return data says nothing about the density of points that actually make it to the ground.

You might question the fact that a low power drone LIDAR system was used in this example. However, you will observe poor ground penetration in any LIDAR system when using pulses far from nadir (large scan angle), when vegetation are wet and numerous other scenarios.

Till next issue, remember to look below the skin to access the true beauty of a point cloud!

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.

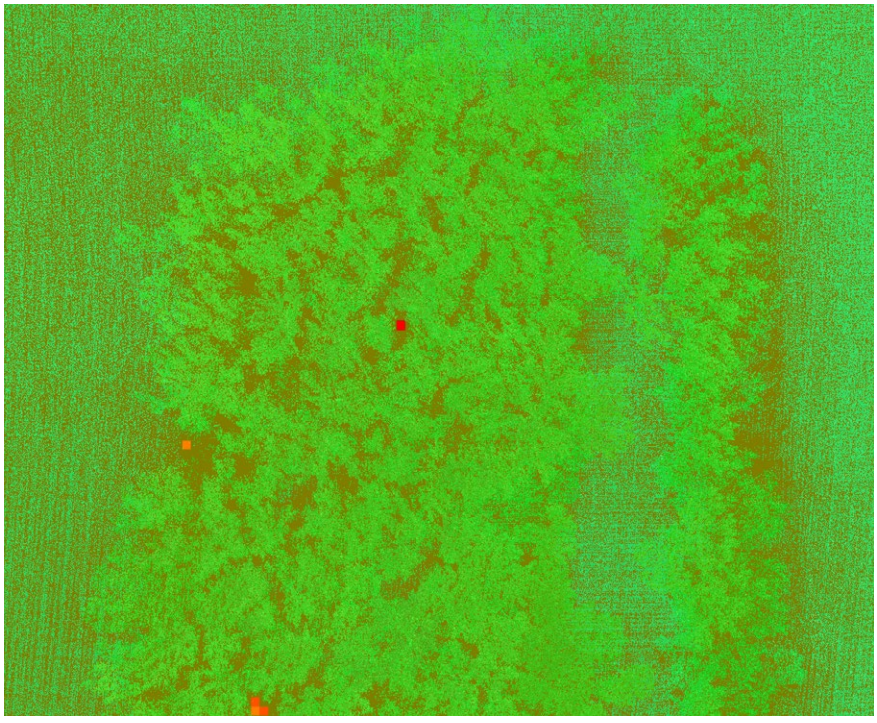


Figure 2: "All Points" Density Test

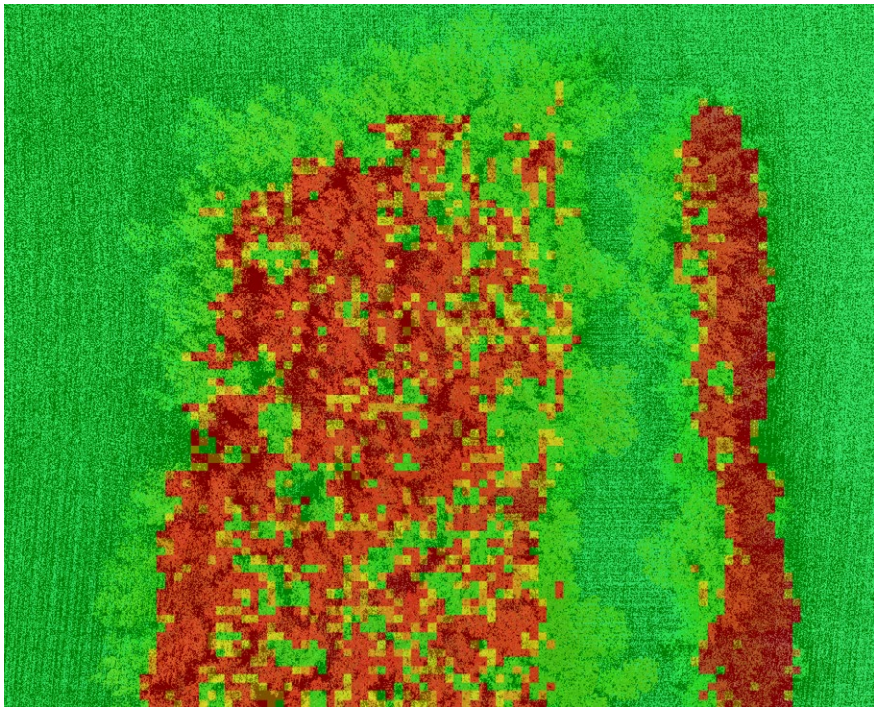


Figure 3: Ground Class Density Test

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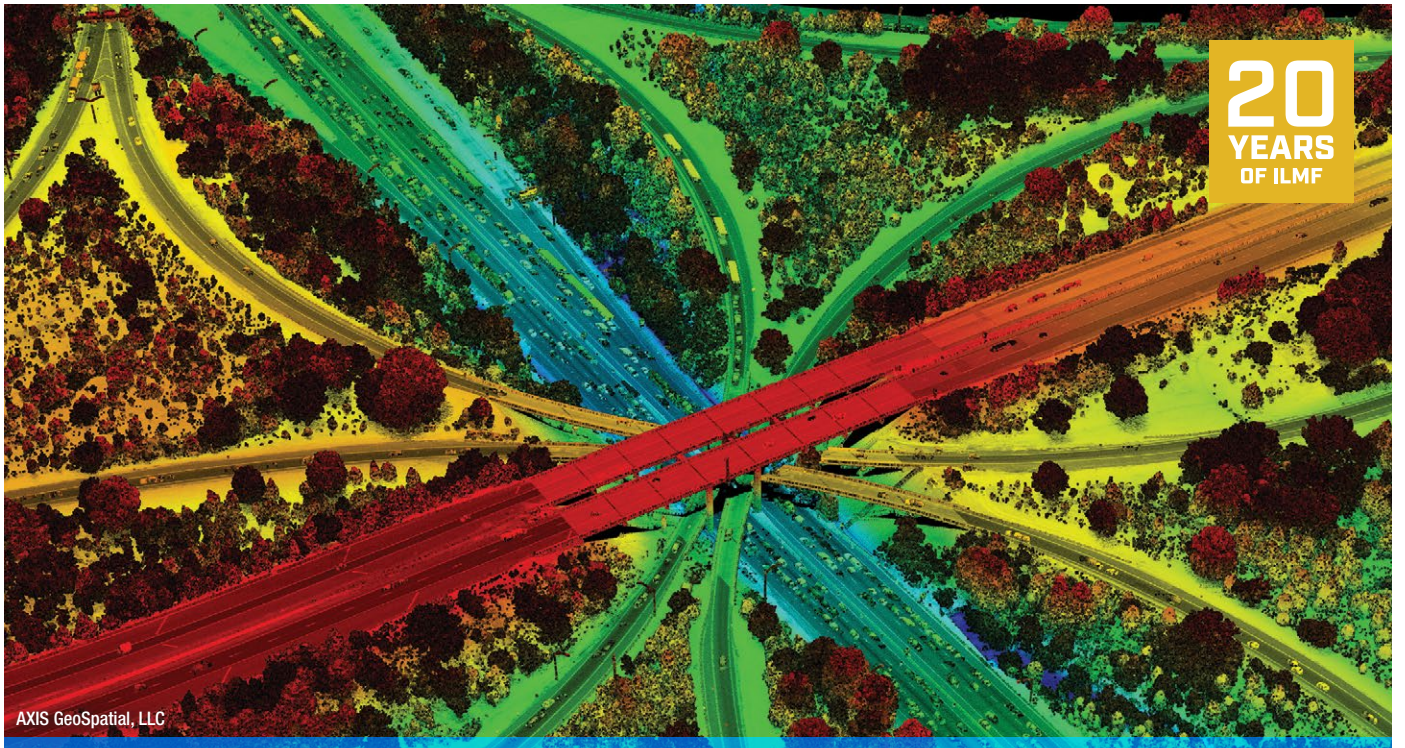

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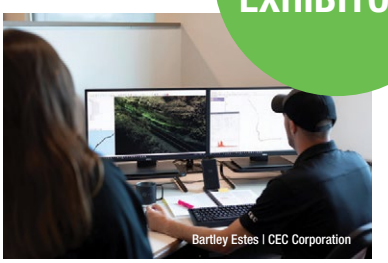

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I was recently involved in a detailed discussion of various metrics of processed airborne laser scanning (ALS) data that can be used as pass/fail criteria for the quality of the data. At the time of the assessment, the data are cleaned of noise, classified to ground, vertical accuracy assessed and tiled.

While the primary discussion revolved around point density, it expanded into other factors related to generating valid derived products, most especially digital elevation models (DEM) of the bare earth. One area of discussion was the practice of using the density of the overall first return LIDAR data (excluding *withheld* points) as a proxy for the bare earth point density.

My argument is that we really must focus on the product that is to be derived from the point cloud data. For example, imagine trying to use point density of first return data of a photogrammetrically derived point cloud as a test for adequate density for generating a ground DEM over a forested region. We might have no ground points whatsoever yet our test (since we are considering first return points, regardless of surface) would say we had super high density!

OK, maybe that is a stretch since (nearly) everyone now knows we cannot use photogrammetrically-derived point clouds in vegetated areas. So instead, let's look at LIDAR data. In **Figure 1** is shown a QC check area of LIDAR data collected by a Velodyne VLP-16 sensor flown at an above ground level (AGL) of 75 m. The point cloud is colored by elevation and modulated by intensity using GeoCue's LP360/True View Evo software. You can clearly see we have an area of moderate vegetation (trees) surrounded by an open field. The definition of the vegetation looks great and we seem to have very nice coverage.

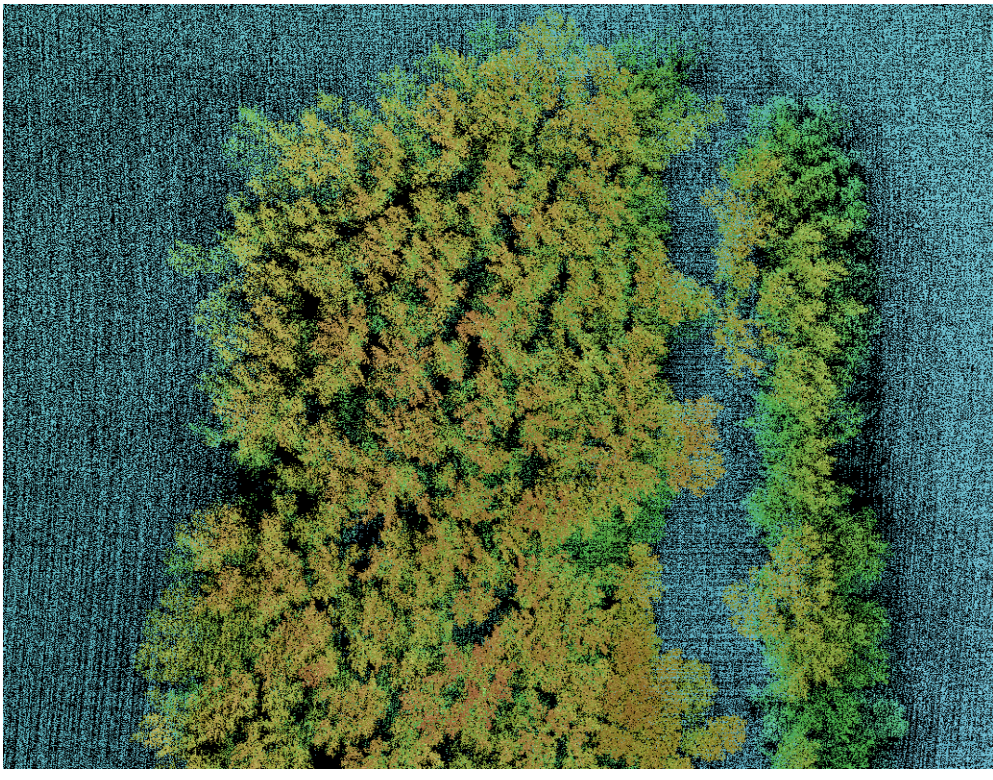

Figure 1: The QC Site (colorized by elevation)

LP360/True View Evo contains a QC tool for measuring point cloud density. You specify a grid cell size and a density ramp and the software generates a colorized GeoTIFF image. For example, if I specify a cell size of 1 m and a point density of 2 points/m^2, the software will create an image with green pixels where the density equals or exceeds 2 points/m^2 but yellow, orange and finally red pixels as the density vanishes to zero. **Figure 2** shows an image using *all first return points*, regardless of the type of surface from which they are reflected (ground

continued on page 46

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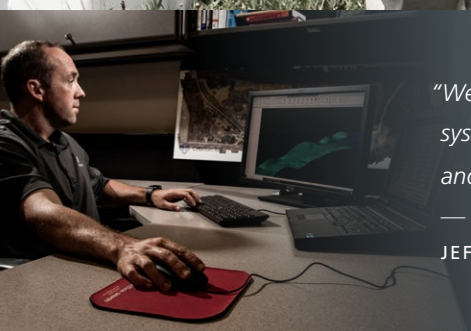

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