VOLUME 12 ISSUE 1

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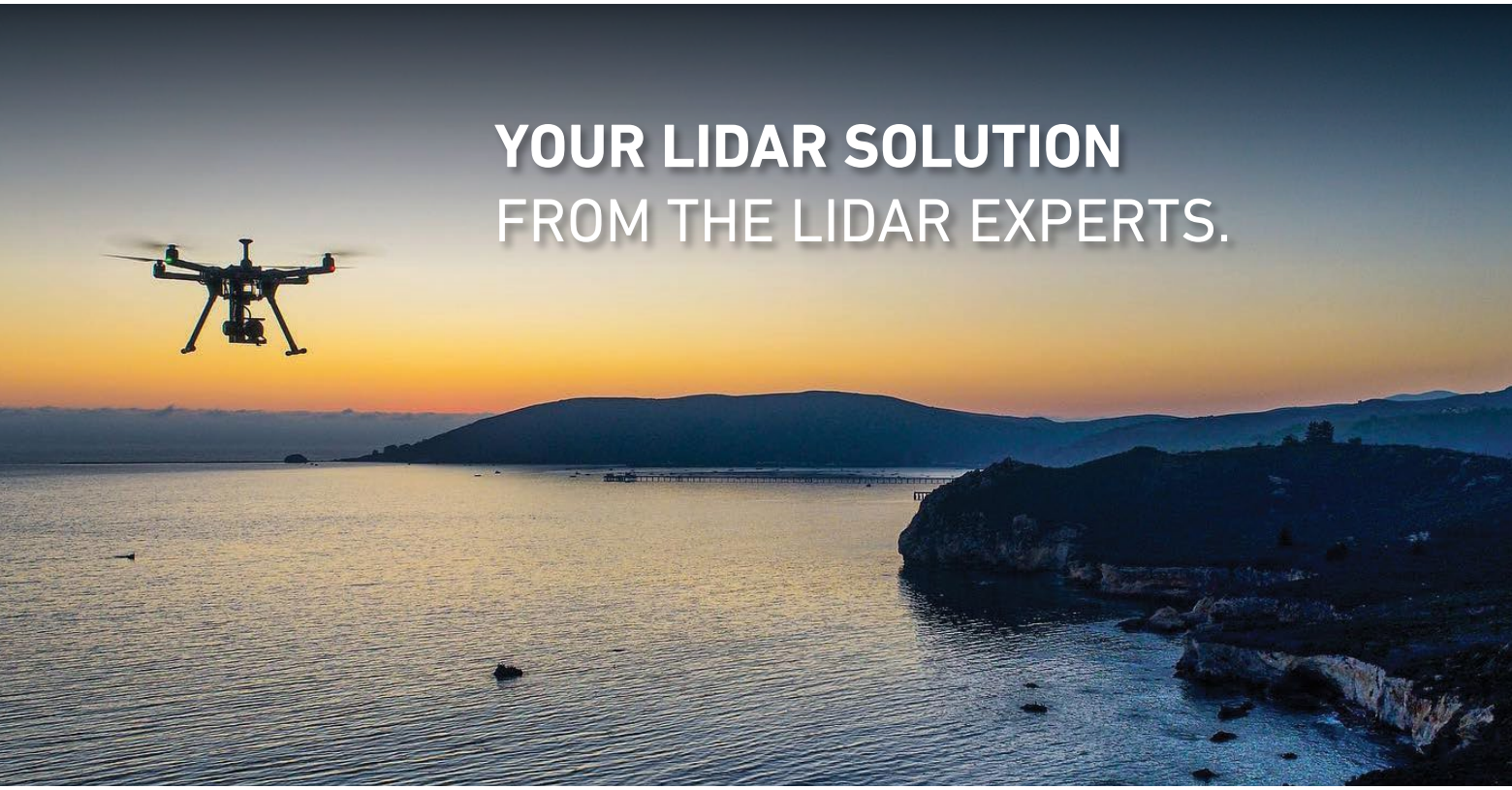

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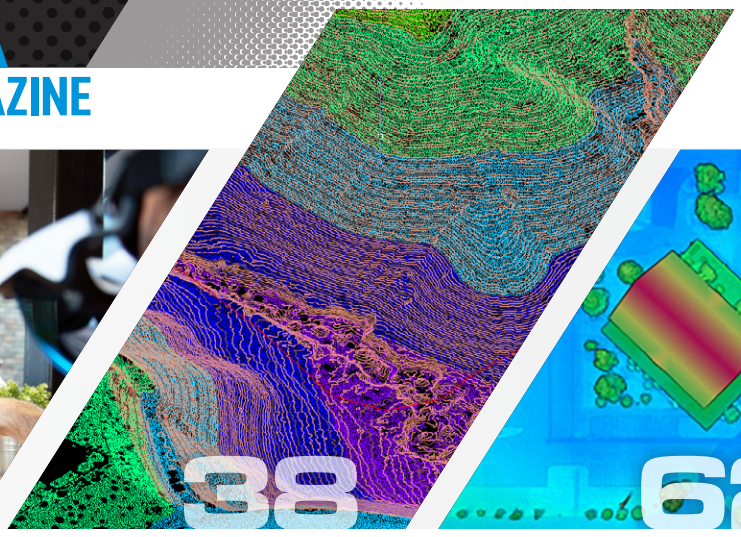

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◀ ON THE COVER

Airborne lidar collection of a western highway interchange, courtesy of Aero-graphics. www.aero-graphics.com

COLUMNS

SPECIAL SECTIONS

LIDAR To Go!

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DR. A. STEWART WALKER

Panglossian? It's a good time for lidar

Many of you, I hope, will read this during the Geo Week conferences in Denver in February 2022. At the time of writing, we remain concerned about the seriousness of omicron's threat—but we're making travel plans. The year has opened well for hellenists, whose education is often derided these days. Our knowledge of the *alphabet*, for example, enables us to understand the long road ahead, from *omicron* onwards, as *pandemic* becomes *endemic*. Meanwhile, *democracy*, a term originally coined to describe electoral systems in Greek city-states in the fifth century BC, seems destined to become a 20th century relic as countries occupied by most of the world's population use, or are about to adopt, more modern political systems.

Enough etymological sophistry! Where are we now? Geo Week offers a thrilling technical program, a packed exhibition eagerly anticipated by symposiasts[1] and exhibitors alike, strong co-located events, and the presentation of awards, including the Lidar Leader Awards, a joint initiative of Diversified Communications and this magazine. *LIDAR Magazine* is elated that the adjudication process deemed Martin Isenburg worthy of the Outstanding Personal Achievement in Lidar Award. This is the first posthumous Lidar Leader Award and we hope readers share our recognition of this remarkable lidar guru who left us so very early[2]. The Outstanding Team Achievement in Lidar Award goes to Minnesota 3DGeomatics Committee, an exemplar of dedicated groups of scientists, bureaucrats and other lidar professionals and proselytizers, especially in government at all its levels, toiling in the evangelical and educational trenches both internally and outside their organizations, before an RFP for lidar data collection is even issued. The Outstanding Enterprise Achievement in Lidar Award has been won by the French company Outsight for its Augmented Lidar Box and the Outstanding Innovation in Lidar Award belongs to Australian visionary Emesent for its Hovermap, a scanning unit for drones to provide autonomous mapping in challenging, inaccessible areas such as mines. The Outstanding University Achievement in Lidar Award will be decided at Geo Week. As always, a host of nominations was received for all the awards and the decision-making was tough—we are grateful to those involved. These Awards have proved popular and symbolic. Long may they continue.

We have advertisements in this issue for two live events later in 2022: the annual AUVSI meeting, called XPONENTIAL 2022, which takes place in Orlando in April; and the XXIVth ISPRS Congress, in

1 Attendees at a conference or meeting; the word is derived from the Greek for "fellow drinker"!

2 https://lidarmag.com/?s=isenburg

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Nice, France, in June. These will both be memorable, for lidar and much more. We admire Diversified Communications, AUVSI and ISPRS for navigating the tumult to enable us to learn and network.

As a veteran reader of claims about the demise of photogrammetry, I'm not surprised when similar assertions are made about lidar. Rand Voorhies, CTO and co-founder at inVia Robotics, is of the opinion that lidar is being superseded in robotics by 2D imaging sensors assisted by machine vision and deep learning[3]. But he admits that his argument is focused on robots working indoors, whereas lidar's role on outdoor vehicles is undisputed. Here's another thought. Most readers of this magazine are familiar with large sensors mounted on crewed aircraft or rather less expensive ones on UAVs. Sales of sensors of the former type number in the low hundreds per year; in the latter, the thousands. Think, however, about an automotive lidar supplier making a sale to a car manufacturer or tier one supplier for ADAS purposes: such a contract could involve hundreds of thousands of vehicles, maybe even more, with one or more lidar sensors in each. And the even bigger AV market is just arriving! Those of us in the geospatial world will continue to benefit from the cheaper, better sensors that these massive contracts—and the competition to win them—engender.

The articles in this issue are, in different ways, associated with trends. Many of them are summarized by Qassim Abdullah, Woolpert's brilliant lidar luminary, in the latest of a series of annual predictions that began life as a blog on the Woolpert website[4]. His comment on lidar in robotic vacuum cleaners is an unintended counterpoint to Voorhies! We are honored to publish this jointly with *Photogrammetric Engineering & Remote Sensing*, one of the truly great geospatial journals round the globe, and the Geo Week newsletter. Abby Chew of Phoenix LiDAR Systems recounts her company's relocation from Los Angeles to Austin, the eastward trek championed by Elon Musk among others[5]. The move went well and Phoenix has embarked on a new product line, RECON, aimed at prospects with less deep pockets than the existing customer base.

We've published many articles by the big US geospatial services companies. Some describe themselves as AEG—architecture, engineering and geospatial. Yet, regardless of nomenclature, most of them go beyond just the acquisition and processing of geospatial data and offer a broader range of services. Sometimes we are not fully aware of their strength and reach. NV5 has grown dramatically in recent years, for example, partly through a series of acquisitions. As a result, it has a facility close to my home office where NV5 centers much of its UAV sales and operations. This came about as a result of acquisitions and I was invited by regular magazine contributor Mark Meade and local manager Mike Stys to visit and see what was going on. This is reported here and it's intriguing that NV5 lays special emphasis on the proper integration of its acquisitions in order to maximize the resulting synergies.

Many readers were excited about Woolpert's acquisition last September of AAM and Optimal GEO, the leading global geospatial services companies headquartered in Australia and Alabama respectively. Like NV5, Woolpert is poised to capture synergies, without which acquisitions hold less allure. *LIDAR Magazin*e hopes, moreover, to benefit in the form of more articles from the southern hemisphere.

Acquisitions can also have the opposite effect. Many readers will be disappointed that there is no "Random Points" article in this issue. The reason is that GeoCue Group, of whom columnist Lewis Graham was president and CTO, has been acquired by mdGroup, which owns the well known UAV supplier Microdrones. We congratulate Lewis and wish him well on the next phase of his career. We also thank him warmly for a stream of thought-provoking pieces. Lewis and his team grew GeoCue through years of endeavor. We hope they are enjoying the fruits of their labors.

I end with an apology. I couldn't resist some irony at the beginning. Though "panglossian" includes the Greek word for tongue in its derivation, it's mainly drawn from the name of the tutor and philosopher in Voltaire's satire *Candide*. Nevertheless, a surge of excessive optimism may be just the thing to carry us, like technological surfers, into a memorable 2022. After devouring a holiday gift, John Le Carré's masterful *Agent Running in the Field*, I am tackling Dickens's *A Tale of Two Cities*. We've all heard the beginning of the long opening sentence, "It was the best of times, it was the worst of times..." Take the first clause!

A. Stewart Walker // Managing Editor

3 https://www.zdnet.com/article/is-lidar-on-its-way-out/

4 https://woolpert.com/media/blogs/top-7-geospatial-trends-watch-2018/

5 Anon, 2022. City limits: the future of Austin, *The Economist,* 442(9279): 25, 15 January 2022.

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LIDAR LEADERS

LIDAR LEADER AWARDS

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In conjunction with GeoWeek 2022, we've opted to celebrate the accomplishments of leaders in our field at the Lidar Leader Awards, a joint initiative of LIDAR Magazine and the organizers of the International LiDAR Mapping Forum (ILMF). Over the pages that follow, we've highlighted some of the finalists from each award category. As you'll find, the nominations embody a galaxy of lidar talent. All winners will be provided the opportunity to highlight their perspectives in an upcoming edition of the magazine.

Five categories were offered this year:

Outstanding Personal Achievement in Lidar

Outstanding Team Achievement in Lidar *(2-99 members)*

Outstanding Enterprise Achievement in Lidar *(groups of 100+)*

Outstanding Innovation in Lidar

This category was created to honor recent projects or products that appear to be ground-breaking.

Outstanding University Achievement in Lidar

This category is open to all universities, students and teams within the university, who must demonstrate an exceptional achievement within the realm of lidar technology.

Editor's note: The text that follows has been excerpted from original nominations and in no way defines the views or opinions of the award committee, the organizers of ILMF or LIDAR Magazine. Some text has been edited for clarity and length.

Congratulations to the following finalists...

Personal Achievement in Lidar
Dr. Martin Isenburg (1972-2021)

Dr. Isenburg was the creator of the widely used LAStools, LASzip, and PulseWaves software packages, and he operated Rapidlasso GmbH while providing commercial and open-source software for lidar data processing, exploitation, compression, and organization. Martin was a vocal advocate for the release of public scan data. He frequently gifted his software tools to groups through the "LASMoons" program to allow students and organizations to use LAStools to achieve specific academic and ecological lidar data processing tasks. Not only did this program show users how to effectively use the software, it demonstrated the worldwide thirst for lidar data acquisition, processing, and compression.

Outstanding Enterprise Achievement
Augmented LiDAR Box by Outsight

Outsight develops real-time 3D LiDAR perception solutions. Our mission is to make LiDAR-based Spatial Intelligence become Plug & Play, so it can be used by application developers and integrators in any market. The Augmented LiDAR Box is the first LiDAR pre-processor: a real-time software engine that turns any LiDAR into a Spatial Intelligence device. It overcomes the complexity of using RAW 3D data, so any application developer or integrator can efficiently use LiDAR in its own solutions without needing to become a 3D LiDAR expert.

Team Achievement in Lidar
Minnesota 3DGeomatics Committee

Minnesota was an early adopter and national leader for statewide lidar technology, affording a unique understanding of the ongoing need for higher data quality. The 3D Geomatics Committee (3DGeo) of the Minnesota Geospatial Advisory Council works to identify and promote the need for planning, funding, acquisition, and management of three-dimensional geomatic data and derived products, such as lidar. Geomatics is the discipline of gathering, storing, processing, and delivering spatially referenced geographic information. The 3DGeo Committee engages multiple disciplines in Minnesota to promote the value, importance, and use of this complex and voluminous three-dimensional information.

Outstanding Commercial Innovation
Hovermap by Emesent

Founded in 2018, Emesent is a world-leader in drone autonomy, LiDAR mapping, and data analytics. Emesent's Hovermap is a smart mobile lidar scanning unit that can be mounted to a backpack, vehicle, or drone to quickly map complex environments. When mounted to a drone, Hovermap also provides collision avoidance and autonomy to map inaccessible or GPS-denied areas. It is equally capable above ground, under bridges, or up close to critical infrastructure. Hovermap's accurate, high-resolution point clouds can be easily processed into CAD-ready datasets to build 3D models using industry standard tools, such as PointCab, PointFuse, or Revit/AutoCAD.

Figure 1: Newly developed software platforms enabling virtual collaboration have taken virtual and augmented realities to new levels.
Image courtesy of Getty Images

Top Geospatial Trends to Watch in 2022

Ten pointers from an industry luminary

BY QASSIM ABDULLAH

As we celebrate the end of a difficult year and look ahead to what 2022 holds, many of us are thankful for the good health we maintained while many of our friends and family members were not as fortunate. The pandemic has imposed many daily challenges and created a sense of urgency that we had never witnessed before. Driven by the need to rebuild our economies and regain some sense of normalcy, this has inspired the need to bridge the vast digital divide between advanced geospatial professionals and those who require these solutions but are less technologically savvy.

Regardless of where people fall on that continuum, the need to work and

> “Despite the pandemic changing how we conduct business, geospatial sensor manufacturers and technologies continued their upward trend, although more modestly than expected.”

communicate virtually has permeated all sectors of global society. “Zoom” became a common household term for all ages and abilities, while that platform and others like Microsoft Teams have provided vital corporate lifelines around the world. Curbside grocery pickup and virtual doctor visits also became the norm, while fitness centers have been replaced with remote Zumba classes and home gyms.

These digital demands presented great opportunities for this advancement of cloud-based data sharing and processing, which directly and indirectly resulted in improved 3D processing and modeling. Despite the pandemic changing how we conduct business, geospatial sensor manufacturers and technologies continued their upward trend, although more modestly than expected. In the following, I will revisit my predictions on geospatial trends made at this time last year, while looking ahead to what’s expected in the industry this year.

Virtual collaboration rooms and mixed reality

Although developments in virtual and augmented reality started long before 2021, the lowered costs of data processing, computing power, algorithms, data compression and the cloud processing platform have advanced these technologies from video games to engineering and environmental solutions with direct societal benefits.

The release of Microsoft Mesh, a software platform for virtual collaboration, has taken VR and AR to a new level. Within Mesh, team members who are continents apart can engage via eye contact, facial expressions and gestures as 3D avatars in a shared space, collectively discussing and implementing modifications to a 3D replica of their project or design (**Figure 1**). Team members can participate in a Mesh session using Microsoft HoloLens 2, VR headsets, mobile phones, tablets or PCs via a Mesh-enabled app. HoloLens 2 is a self-contained holographic computer that enables hands-free and heads-up interaction with digital models via eye goggles.

These accessible platforms generate the need for 3D data while providing a new means of data modeling and interpretation. The geospatial industry reaps the technological fruits of these platforms when these applications involve 3D data modeling for engineering and environmental projects. Bentley, for example, has released its mixed reality platform, SYNCHRO XR, an app designed for visualizing 4D (3D data plus time) construction digital twins that also uses HoloLens 2.

A similar approach was introduced this year by NVIDIA with its NVIDIA Omniverse platform, which is described as “a scalable, multi-GPU, real-time reference development platform for 3D simulation and design collaboration, based on Pixar’s Universal Scene Description and NVIDIA RTX technology.”[1] Omniverse enables a variety of client applications, renderers and microservices to share and modify representations of virtual worlds.

Deep into miniaturized sensors

Apple achieved a great milestone in 2020 with the introduction of a lidar sensor on its iPhone 12 Pro, and it continued that capability on the iPhone 13 Pro. As a result, we have witnessed more surveyors and field technicians using smartphone-based lidar. A technician repairing a faulty circuit in an underground manhole can use this easy lidar tool to document and create an above-ground or underground 3D model. Many articles published last year summarized applications and data accuracy verification of point clouds from iPhone 12 and iPhone 13, providing an expanding and accessible way for people to benefit from geospatial technologies.

Miniature lidar has been used on automated vehicles for a few years, and

1 https://developer.nvidia.com/nvidia-omniverse-platform

similar technology has been adopted for advanced home cleaning robots like the Samsung Jet Bot AI+ Robot Vacuum. The cleaning robot is equipped with a lidar system and SLAM navigation hardware to scan and map rooms in a building, guided by geofencing to address defined cleaning needs. The manufacturers of these vacuums are not using the laser for range-finding and obstacle-avoidance: the laser is part of a true mapping system.

Dreametech, Narwal and iRobot have followed a similar design approach to Samsung and added lidar to their products. These developments should be welcomed by our industry as they illustrate how miniaturized lidar systems can be used, with slight modification, on board mapping drones. These expanding applications will propel more advances in lidar manufacturing and will help bring down the cost of lidar systems.

BIM and GIS, the foundation for digital twin and metaverse

2021 brought a noticeable focus on the digital twin, with the industry learning more about its value to society. We also started hearing the term "metaverse," which is synonymous with, or at least close to, "digital twin". Often misunderstood and confused with a 3D model, a digital twin is much more complex. It encompasses multiple concepts—such as scan-to-BIM, 3D modeling and GIS—to produce the desired environment.

Over the course of the year, the industry has learned that a digital twin:

- Is a dynamic, up-to-date replica or representation of a physical object, asset or system with a complete collection of data in one place
- Evolves with the flow of real-time input from sensors and other sources
- Is not a static 3D model or simulation, but continues to evolve with added data and information

This advancement is important because, to those without a full understanding of the digital twin and its value, the term would remain an abstract buzzword. The digital twin, BIM and smart city concepts share the overarching goal of managing data and information as a smart and interactive means of improving data accessibility for better decision-making and asset management.

The digital twin accelerates asset operational readiness as it transforms an asset's life cycle with the use of maintenance and performance data. **Figure 2** illustrates the stages in an asset's life cycle when viewed through the digital twin lens: design details do not end up as a static archive in someone's office but evolve into a living link to inform the asset owner or the operation manager to produce informed decisions.

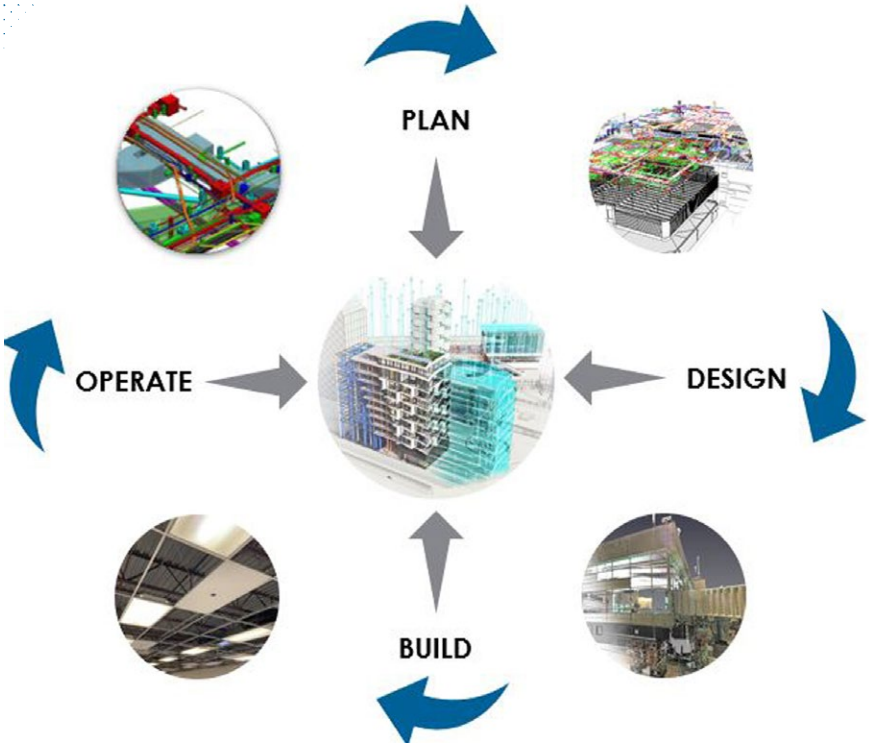


Figure 2: When viewed through the lens of a digital twin, design details become living links to support more informed decision-making.
Image courtesy of Woolpert

Experts believe that about 70% of the return on investment in an asset design ecosystem is realized through asset operation and management. Today's asset owner wants digital data at the outset, so project designs and models do not end up trapped in files (PDFs, spreadsheets, etc.); they live in dynamic objects that are easily accessed and managed. Without the digital twin approach, analog, unclassified and disconnected data present management challenges. This connection between the digital and physical worlds offers enhanced life cycles, informed decision-making and predictive capabilities.

Although our knowledge of these innovative concepts and their applications grew at a healthy pace in 2021, there still needs to be more outreach to educate clients and the industry about their collective benefits. Fortunately, a growing number of agencies and property owners understands the ROI and is willing to invest in building a digital twin for projects or assets. Architecture, engineering and geospatial (AEG) firms have a great opportunity to serve their clients by collecting, modeling, and managing data and building an integrated digital twin/BIM environment. This provides for better access to data and information to support efficient and effective asset management. The digital twin also opens huge opportunities for the geospatial community, since it relies on services like scan-to-BIM, lidar scanning, GIS and other mapping processes.

High-definition maps for autonomous driving

The concepts of smart cities and intelligent transportation systems continued to make progress in 2021. In particular, developments in autonomous driving made strides as an increasing number of car manufacturers worked toward putting their autonomous vehicles on the road in the next five to 10 years.

While connected and autonomous vehicles are equipped with a variety of sensors and artificial intelligence algorithms to help navigate the road, they also require high-quality maps to see beyond the vision of the onboard sensors and to assist during inclement weather. These maps are not like the navigation maps you see on a smartphone or a standard car navigation system: They are high-definition maps. These maps provide the car control center, i.e. the brain, with extensive, precise information: for example the lane number the car is in, freeway exit lanes, pedestrian crosswalks, bridges, overpasses, tunnels, locations of traffic control devices, smooth 3D trajectories for road edges and boundaries that are accurate to the centimeter level, meter-by-meter road grade and road superelevation.

Most self-driving vehicle manufacturers are planning to develop these maps for their vehicles. The exception is Tesla, which ascribes to autonomous navigation using sensors alone. Opponents of this sensors-only approach cite the following advantages of utilizing high-definition maps, which:

1. Have a longer range than sensors, with views for miles that wrap around corners and curves
2. Help the car drive smoothly around curves versus the jumpy updates of live sensors
3. Provide more accurate positions than sensors
4. Enable continual updates and improvements; sensors are static unless you get a new car
5. Can be used for car geofencing
6. Are not impacted by weather conditions, unlike sensors
7. Can be used to check and verify the health of sensors, providing an extra layer of safety
8. Can correlate traffic lights to lane assignments

Although these are proven benefits, high-definition maps for the global roads network do not yet exist for autonomous vehicles. Tremendous work and global cooperation are needed to remap the roads network to this level of detail. Some car manufacturers are attempting to build these maps themselves but are finding the job daunting. Additionally, they are producing maps according to their own specifications, which not only leads to a duplication of efforts but also creates an inherent and troubling lack of standardization.

The geospatial industry has an immense opportunity to work with national and global transportation agencies to put forward a set of standards to govern the production of high-definition maps to support autonomous vehicles (**Figure 3**). The industry can not only ensure that the maps are created appropriately but also earn a substantial market share of the services and technologies needed to produce high-definition maps for a global roads network.

Drones, drones everywhere

While unmanned aircraft systems have been used for engineering and geospatial mapping applications for several years, 2021 finally saw industry standardization. On the regulatory side, the Federal Aviation Administration issued positive modifications to Part 107 guidelines regarding flying restrictions over people

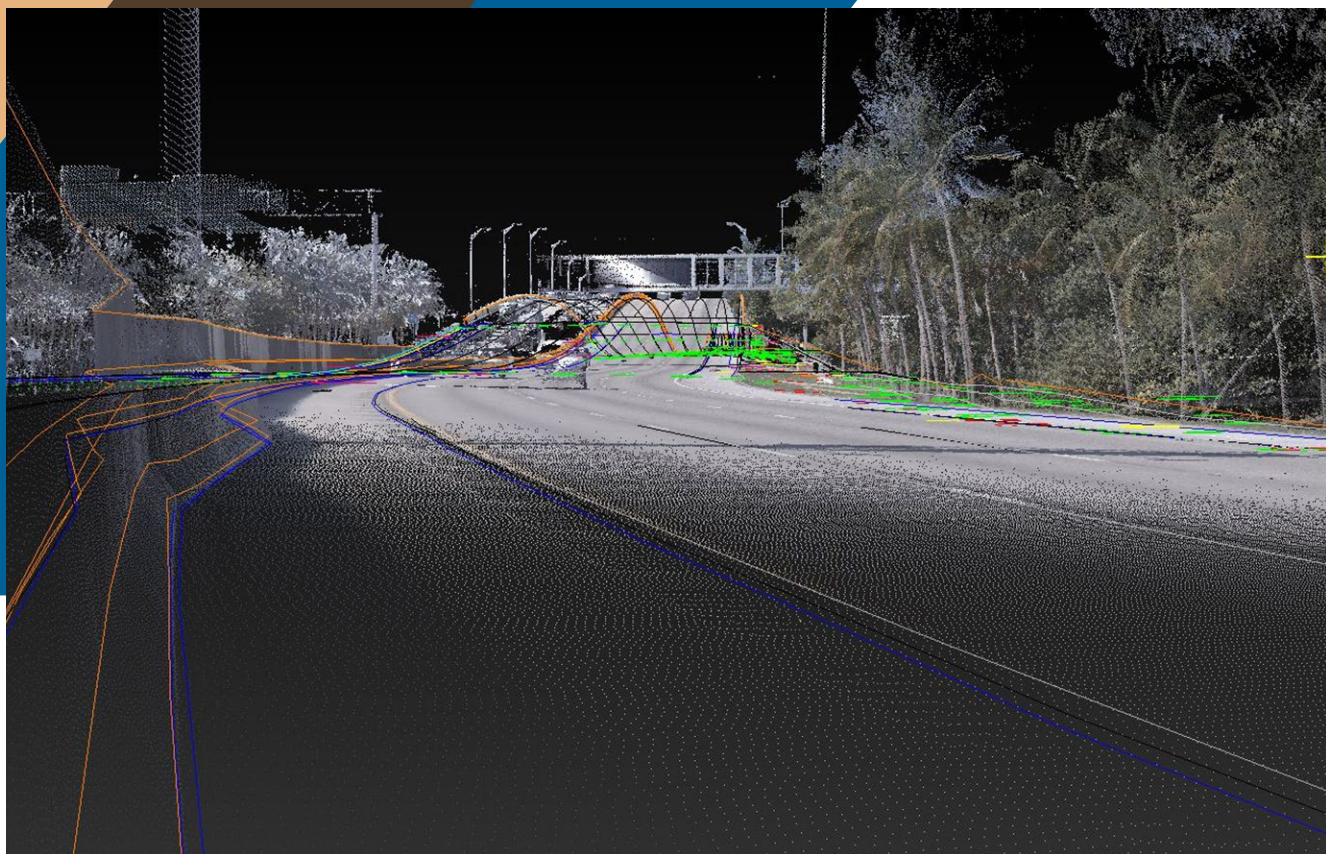


Figure 3: The geospatial industry has an immense opportunity to work with national and global transportation agencies to put forward a set of standards to govern the production of high-definition maps to support autonomous vehicles. Lidar and imagery data, as collected here in Florida in 2020, would support the accuracy of those maps.

Image courtesy of the Florida Department of Transportation

and flying at night. This enabled drones to become integral to professional aerial data acquisition operations. Improved business practices and advancing technologies have helped prove when it comes to small projects, there are no other acquisition platforms that can compete with drones' capability and affordability.

The other strong dynamic that 2021 brought to drone operations was the increase in UAS-based lidar. This healthy growth was helped by the release of DJI's lidar system, Zenmuse L1, which "integrates a Livox Lidar module, a high-accuracy inertial measurement unit, and a camera with a 1-inch CMOS on a 3-axis stabilized gimbal"[2]. Zenmuse L1 is offered with DJI's newest drone, the Matrice 300 RTK, and DJI Terra, which is DJI's suite of software for mission planning, data capture, and data processing and analysis. The differentiator for the DJI lidar solution is the lower cost as compared with other market offerings, which attracted the attention of small businesses and solo operator companies.

While the Zenmuse L1 provides a reasonable solution for many applications, it will not be suitable for applications that require the highest accuracy. Zenmuse L1 is marketed with accuracies of 5 cm vertical and 10 cm horizontal (RMSE). While the 5 cm vertical accuracy is suitable for many applications, it will not meet standards for road design as required by departments of

2 https://www.dji.com/zenmuse-l1

transportation. I expect that this growing trend in collecting lidar data via drones will continue through 2022 and in the years to come.

From coastal and deep into the sea

As I predicted last year, bathymetric survey and data collection made industry news in 2021, partly due to the direction the global economy is taking to support and protect the blue economy. Multiple aspects of our life—from fisheries, aquaculture, maritime transport, coastal and marine and maritime tourism to the emerging utilization of marine spaces to harness coastal wind energy—contribute to the evolving blue economy and require updated approaches and technologies.

Here in the US, deep-ocean survey and advanced techniques for coastal and deep-ocean mapping are in high demand, propelled by two high-profile initiatives of the National Oceanic and Atmospheric Administration (NOAA): National Strategy for Ocean Mapping, Exploring and Characterizing of the United States Exclusive Economic Zone (also known as the NOMEC Strategy) and Alaska Coastal Mapping.

On the coastal and inland-water mapping front, mainstream lidar manufacturers continued to make innovations and enhancements for topographic and bathymetric systems. Recently we witnessed some creative developments in bathymetric lidar initiated by industry members outside traditional manufacturers. An example of this was the recent introduction of the first high-altitude topobathymetric lidar system, based on Geiger-mode technology. The Bathymetric Unmanned Littoral LiDar for Operational GEOINT (BULLDOG) system was developed by the Woolpert Maritime Research Lab for the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX)[3].

Additionally, deep-ocean hydrographic surveys witnessed good progress in the field of uncrewed deepwater mapping technologies. Companies like SailDrones and other manufacturers are expected to continue to innovate to meet demand.

Data democratization: big data needs big tools

In my opinion, the field of data democratization grew sluggishly in 2021 as businesses struggled to survive a challenging year. We did not see clear signs from the mainstream geospatial industry of the growth of creative methods and tools to mine, extract and convert geospatial data into knowledge, and therefore we are still limited in our development of tools that can gather information from lidar point clouds and imagery using automated methods. Despite that, the industry continued its interest in data mining and machine learning as it relates to application development.

Outside the geospatial industry, crowdsourcing, big data and data science continued to grow. This was largely fueled by a hot market for tech companies selling location-based and social tracing data to the highest bidder, whether for business purposes, marketing or otherwise. The diverse sectors utilizing these location-based technologies—including planning, construction, utilities, transportation, government and energy—will continue their growth and potential applications in 2022 and the years to come.

> “Coastal wind energy development found a soft-landing spot within the geospatial industry, since the planning, design and construction of wind farms requires geospatial and surveying services, including bathymetric lidar survey.”

Whirl around the coastal regions

With the current US administration backing renewable resources, the coastal wind energy industry is expected to flourish in the coming years (**Figure 4**). Last year, the nation’s first large-scale offshore wind farm was approved about 12 nautical miles off the coast of Martha’s Vineyard, Massachusetts. More projects are either already approved or in their final stages of approval. This development found a soft-landing spot within the geospatial industry, since the planning, design and construction of wind farms requires geospatial and surveying services, including bathymetric lidar survey.

3 https://lidarmag.com/2021/12/27/next-generation-topo-bathy-sensor/

Figure 4: The planning, design and construction of wind farms requires geospatial and surveying services, including bathymetric lidar survey. With the current US administration backing renewable resources, that industry is expected to flourish in the coming years.
Image courtesy of Getty Images

AI and deep learning are living in the cloud

In my previous articles on annual geospatial trends, I acknowledged that progress was made by agencies moving computing powers to the cloud. More companies are offering business models for cloud data hosting and processing. Amazon, Google and Microsoft continue to lead that market, however, and offer users and developers sophisticated platforms like serverless cloud computing.

As I mentioned above, these platforms enable developers to run apps and services without having to manage and operate costly and complicated server infrastructure. One interesting development is the increased use of and attention to the Microsoft platform Azure, which is a cloud platform that contains more than 200 products and cloud services designed to enable businesses to build, run and manage applications across multiple clouds, on-premises and at the edge, with the tools and frameworks of their choice. Indeed, one very positive characteristic is that it is not limited to Microsoft software and applications. It supports off-the-shelf and open-source technologies, so a user can employ the tools and technologies that suit their needs. Azure supports the virtual work environment, enabling businesses to run any centrally hosted applications using their data source and operating system and device. Because it is virtual, the Azure environment eliminates the need to set up a workstation with company applications and software for every employee individually.

As for geospatial application-based AI within the industry, on the commercial software level, Esri continues to push the envelope to help users streamline workflows with AI tools within ArcGIS. For example, in 2021, Esri added three ready-to-use geospatial AI models in

the ArcGIS Living Atlas of the World. The first two, which use satellite imagery, extract building footprints and perform land-cover classification. The third classifies point clouds. The interesting thing about these models and algorithms, besides their ability to deal with huge amounts of data, is that they are self-trained and require no additional data training by the user.

On the AI-based services side, only modest activities were observed last year. Companies like Airwork offered a cloud-based solution for extracting information from imagery and lidar point clouds. Although this Airwork offering has been welcomed by the surveying and mapping industry, massive work still needs to be done with AI, machine learning and deep learning to marry automation with GIS and geospatial applications to support mining the tremendous amount of data today's sensors acquire. In my opinion, without federal and public funding to entice creativity in this field, GIS and the geospatial applications will see slow adoption of AI, ML and DL capabilities.

Lidar for everyone

During 2021, lidar use and technologies continued to advance. But, aside from the bathymetric development noted earlier, there was not the big breakthrough from a major lidar system manufacturer I had hoped for in the development of AI-based applications. This would help system users derive information from the enormous, growing number of point clouds with minimal manual processing. However, this lack of investment may have been a casualty of the pandemic and its impact on the economy.

The miniature lidar system was the segment that advanced the most in 2021, driven by car manufacturers, makers of gadgets like smartphones, and drone use. Most upscale models of cars are now equipped with lidar sensors, which are important for autonomous vehicles. This is leading car manufacturers to invest heavily in miniaturized lidar by acquiring manufacturing companies that produce small lidar sensors or indirectly supporting their development.

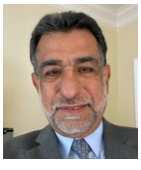
Our industry reaps the benefits from this investment, as Velodyne Lidar is one of the biggest providers of miniature lidar for the automobile companies. Velodyne revealed during Auto Guangzhou 2021, held in China in November, that its latest innovations support advanced driver assistance systems (ADAS), autonomous vehicles, robotics, smart city infrastructure, delivery, industrial applications and more. Fortunately, Velodyne has not yet been acquired by a car manufacturer and still offers affordable lidar systems for our drones.

> "Here in the US, deep-ocean survey and advanced techniques for coastal and deep-ocean mapping are in high demand, propelled by two high-profile initiatives of NOAA."

Shadow of the pandemic

This is my fifth annual trends article, which began as a blog on the Woolpert website in 2018[4]. In the last couple of years, the pandemic has adversely affected many segments of our industry while providing some relief to others. This has made it more difficult to accurately predict where our industry and technology are heading. Nevertheless, one thing has become even clearer during this difficult time: Our success as an industry requires the collaboration of multiple tiers of government, the private sector, public utilities, community activists, building owners, average citizens, etc., to truly advance.

We will get through this, and we will be stronger for it individually and together. Happy New Year!



Qassim Abdullah, Ph.D., PLS, CP is vice president and chief scientist at Woolpert. He has more than 40 years of combined industrial, R&D and academic experience in analytical photogrammetry, digital remote sensing, and civil and surveying engineering. When he's not presenting at geospatial conferences around the world, Qassim teaches photogrammetry and remote sensing courses at the University of Maryland and Penn State, authors a monthly column for the ASPRS journal *PE&RS*[5], and mentors R&D activities within Woolpert.

4 https://woolpert.com/media/blogs/top-7-geospatial-trends-watch-2018/

5 This article is running in *PE&RS*, *LIDAR Magazine* and the Geo Week newsletter.

SPONSORED LISTING INDEX

The following pages provide an overview of key service provider, sensor hardware, software and component part manufacturers, in addition to system integrators. Visit the online directory at *www.lidarmag.com* for additional listings.

We encourage you to visit our sponsors.
Thanks to all that participated in this year's edition.

LISTING INDEX

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GEO WEEK

AEC NEXT

INTERNATIONAL LIDAR MAPPING FORUM

SPAR3D

LIDAR MAGAZINE

Recognize and celebrate excellence in the geospatial market!

LIDAR LEADER AWARDS

BROUGHT TO YOU BY GEO WEEK & LIDAR MAGAZINE

The 2022 Geo Week Award Ceremony will include the Lidar Leader Awards, honoring the achievements of individuals and teams working in the geospatial technology space. Know of a peer, or coworker you can nominate?

Visit **geo-week.com/2022-geo-week-awards** to complete the Nomination Form.

Winners will be recognized during a ceremony on Monday, February 7 at Geo Week.

FEBRUARY 6-8, 2022
DENVER, CO - USA
geo-week.com

INDUSTRIES SERVED

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- Surveying & Mapping
- Urban Planning/ Smart Cities

Produced by diversified

Phoenix LiDAR Systems

APPLICATIONS

- MAPPING
- SURVEYING
- UAV
- GIS
- MODELING
- IMAGING
- SCANNING

COMPANY PROFILE

Phoenix LiDAR Systems was the first to introduce commercial drone LiDAR to the market, in what is now a global industry. When organizations seek to digitize the physical world, whether for surveying, archeology, film, or more, Phoenix LiDAR builds them a fully integrated UAV LiDAR system, combining our hardware and software with an assortment of sensors to create a customized system that is ready to fly. Phoenix LiDAR Systems builds custom, survey-grade laser mapping systems, and automation software for flight planning, acquisition, and post-processing, enabling clients to collect detailed, 3D topographic information for a wide range of commercial and research applications, including engineering, construction, mining, and more.

2113 Wells Branch Pkwy W, Building 1 - Suite 4000, Austin, Texas 78728, US
(323) 577-3366
info@phoenixlidar.com

www.phoenixlidar.com

Evolving the Capabilities of LiDAR

With the introduction of the RECON series, Phoenix LiDAR Systems is removing barriers to widespread LiDAR remote sensing adoption. The RECON series combines low-cost hardware with Phoenix LiDAR Systems industry leading software, LiDARMill, and is empowering a new generation of professionals like never before.

The RECON series features higher accuracies than competing products (that are based on Applanix or DJI navigation systems), while offering extremely simple, automated post-processing solutions to extract maximum value from each dataset.

Utilizing the LiDARMill online, automated processing platform, raw datasets can be imported straight from a USB drive, with reference and optional ground control data seamlessly integrated. Simple wizards enable advanced processing options like trajectory optimization, LiDAR and camera calibration, AI classification, smart decimation and the creation of high-quality deliverables (contours, DTM/DSM/CHM, pointcloud tiling etc.). A fully registered, colorized pointcloud is produced that is accurate in both relative and absolute terms. Project reports then summarize project performance and verify system accuracy.

Phoenix Lidar Systems is committed to designing the world's most advanced, complete LiDAR solutions. With the RECON + LiDARMill combination, users can deploy a simple toolkit that is able to derive accurate and reliable datasets in a matter of hours. Powerful, affordable, and comprehensive... the RECON series by Phoenix Lidar Systems is now available, and sure to disrupt the remote sensing industry.

Hundreds of datapoints per square meter. Dozens of gigabytes of data. Simple, right?

RECON-XT

Absolute Accuracy
55 mm RMSEz @ 50m Range

Max DJI M300 Flight time
33 Minutes

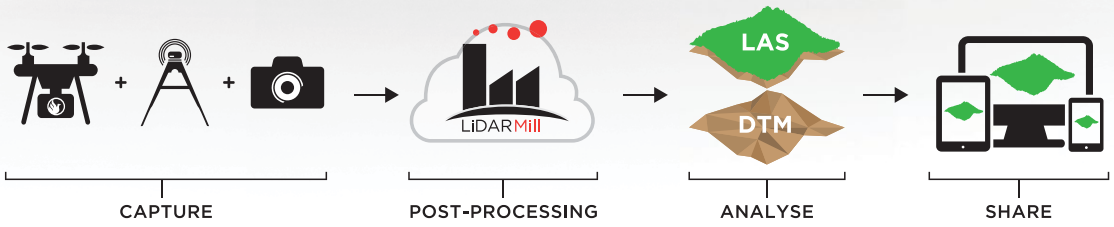
Recommended Scan Height
80m AGL

RECON-A

Absolute Accuracy
3-6 cm RMSEz @ 60 m AGL

Max DJI M300 Flight time
35 Minutes

Recommended Scan Height
80m AGL



Precision laser mapping and post-processing has never been easier. Our elite LiDARMill cloud-based post-processing platform, combined with our cost-effective RECON Series hardware, is the easiest, most complete toolkit available. **AND IT'S ONLY FROM PHOENIX.**

PHOENIX LiDAR SYSTEMS

PHOENIXLIDAR.COM • INFO@PHOENIXLIDAR.COM • (323) 577.3366

APPLANIX

APPLICATIONS:

- AIRBORNE
- MAPPING
- MOBILE
- OEM
- SURVEYING
- INERTIAL/IMU
- GNSS
- UNMANNED/UNCREWED

COMPANY PROFILE

Position and Orientation Solutions
For nearly 30 years Applanix, A Trimble company, has offered complete and customized mobile mapping solutions while championing the technology revolution that allows pinpoint positioning in any condition. Applanix is the standard for organizations that depend on accuracy and quality and who value experienced partners.

Our turnkey and OEM GNSS-Inertial solutions are designed for pinpoint accuracy, efficiency and ease of use, supporting applications for aerial survey and remote sensing, land-based mobile mapping, and autonomous vehicles. Whether you require a complete airborne mapping solution for generating directly georeferenced lidar data or guidance and Advanced Driver Assistance Solutions for vehicles, Applanix has your solution.

applanix™
A TRIMBLE COMPANY

Founded 1991
51-200 Employees
Ontario, Canada

applanix.com

APX-18 UAV

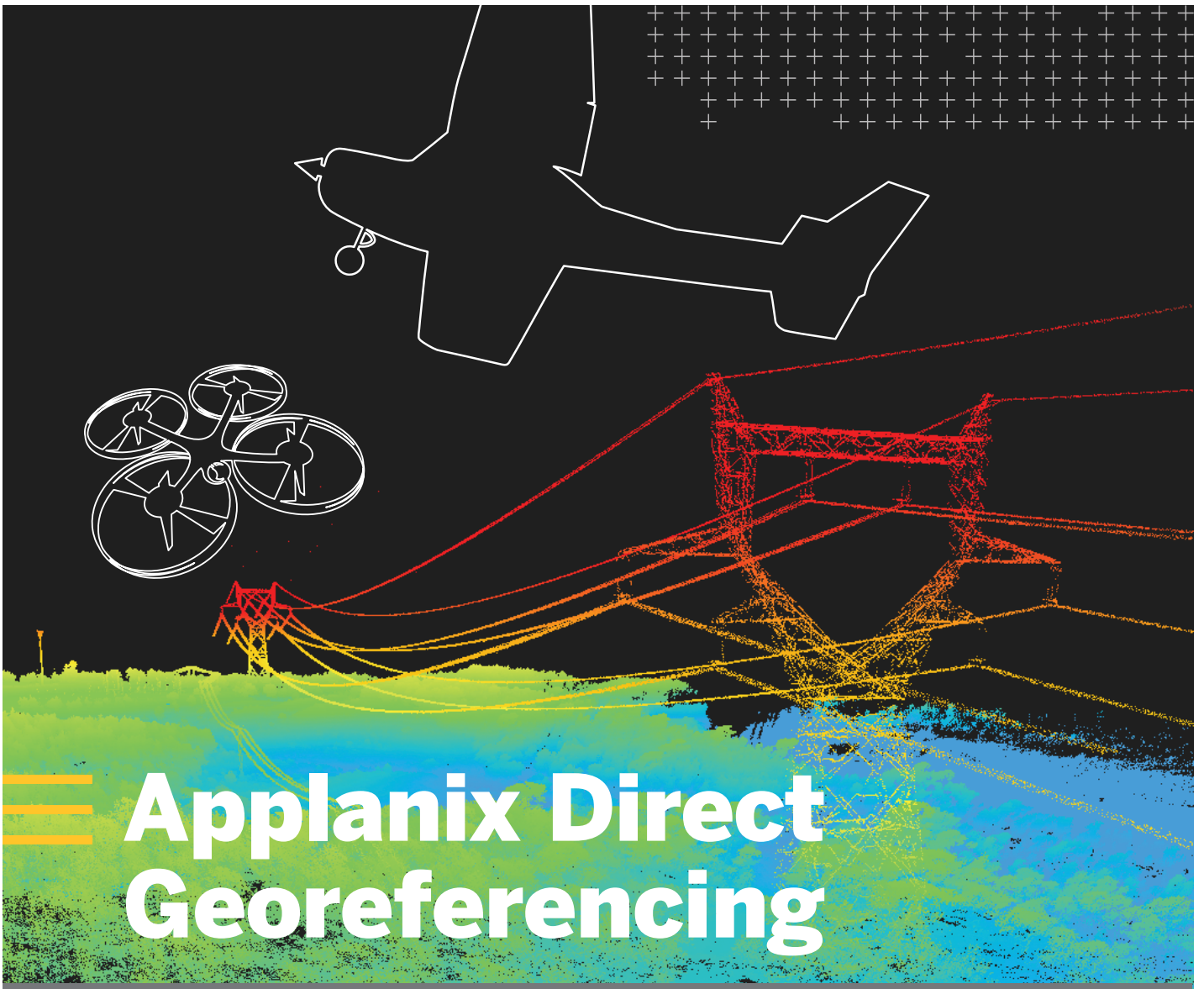
The Trimble APX-18 UAV is an OEM GNSS Inertial solution with dual GNSS antenna input, designed to georeference lidar and other imaging data when collected from Unmanned Aerial Vehicles (UAV) at low speeds or when hovering. Comprised of a small single OEM board containing a precision GNSS receiver with two antenna heading and inertial sensor components plus POSPac UAV Differential GNSS-Inertial office software, the Trimble APX-18 UAV produces a highly accurate position and orientation solution for directly georeferencing lidar point clouds and imagery.

High accuracy, extremely small package

Measuring just 100 x 60 mm and weighing only 62 grams, the APX-18 UAV provides unparalleled performance in an extremely small package. With the included POSPac UAV postmission software, it produces a highly accurate position and orientation solution for direct georeferencing of cameras, lidars and other UAS sensors.

Key features:

- High-performance Direct Georeferencing solution for improved efficiency and accuracy of mapping from small Unmanned Aerial Vehicles
  - Reduce/eliminate GCP's
  - Reduce sidelap
  - Accurate lidar georeferencing
  - Instant alignment through dual GNSS antenna heading
- Compact single-board OEM module complete with survey-grade multifrequency GNSS receiver and MEMS inertial components
- Applanix IN-Fusion™ GNSS-Inertial and SmartCal™ compensation technology for superior position and orientation performance
- POSPac UAV Differential GNSS Inertial post-processing software for highest accuracy
- RTK real-time position for precision landing applications
- Supports all common RTK corrections such as CMR, CMR+, RTCM



Applanix Direct Georeferencing

Turn your aerial vehicle into a professional mapping solution, no matter what you fly!

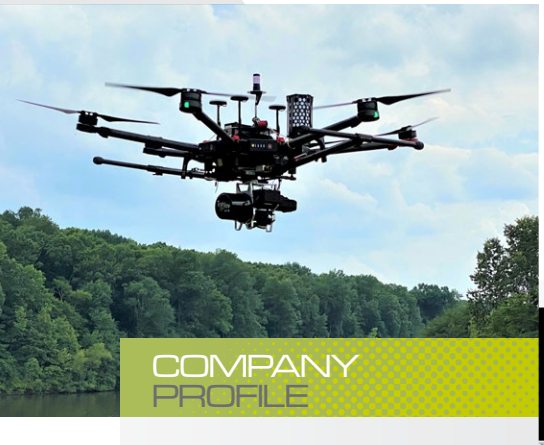
- GNSS-inertial technology specifically designed for Direct Georeferencing airborne sensor data without base stations.
- Applanix DG™ is used with cameras, LiDAR, and hyperspectral sensors for highly-efficient, automated mapping and surveying.
- Experience the accuracy of POSPac MMS/POSPac UAV with Trimble CenterPoint® RTX™.
- Discover Applanix IN-Fusion™ GNSS-Inertial and SmartCal™ compensation technology for superior position and orientation performance.

Applanix Corporation
85 Leek Crescent, Richmond Hill, ON L4B 3B3 Canada
T +1-905-709-4600, F +1-905-709-6027
info.applanix.com/airborne-video
airborne@applanix.com

applanix™ DG™

LIDAR LEADER AWARDS
OUTSTANDING INNOVATION

GEOCUE GROUP INC.



COMPANY PROFILE

GeoCue is the largest supplier of kinematic lidar processing tools in North America and LP360 is one of the world's most widely used tool for exploiting point cloud data. In 2014, GeoCue Group started a division focused on using small Unmanned Aerial Systems for high accuracy mapping. Leveraging our expertise in production, risk reduction, and point cloud processing tools, we are continuing to bring new services and products to market to provide surveyors and other geomatics professionals exciting tools for geospatial data extraction using low cost drones including Loki, our plug-and-play PPK direct positioning system, and now our new True View® Drone LIDAR/Imagery fusion sensors.

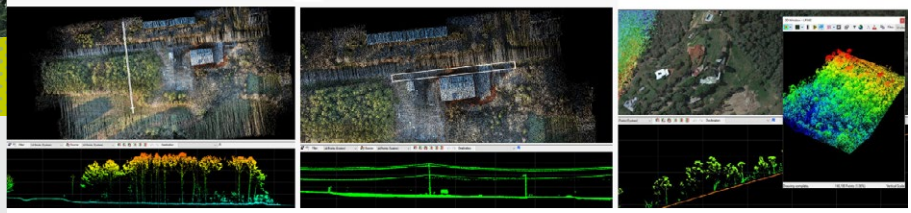
GeoCue Group

Founded 2003
11-50 Employees
520 6th Street Madison, AL 35756

geocue.com

APPLICATIONS

- MAPPING
- PROCESSING
- SURVEYING
- UNMANNED
- AERIAL
- CONSULTING



True View 3D Imaging Sensors

Powerful LIDAR + Dual Camera Sensor integrations, post processing software and data management for high accuracy drone mapping applications.

Fly, Process, Deliver— All in One Solution

GeoCue's True View 3D Imaging Sensors offer an innovative drone mapping solution supporting LIDAR, photogrammetry, and direction geo-referencing solutions integrated in lightweight payloads. GeoCue focuses on offering full solutions rather than individual parts. Unlike other drone LIDAR providers, GeoCue includes post-processing software and a data management portal to provide users with a complete solution from flight to post-processing and data delivery.

Utility-Grade to Survey-Grade 3D Imaging

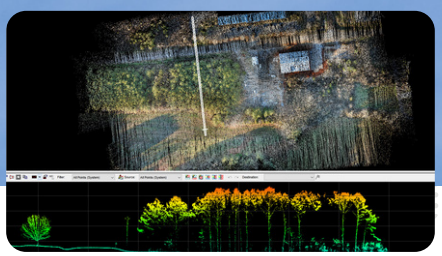
GeoCue offers a series of True View 3DIS systems ranging from utility grade to survey grade ensuring successful drone mapping projects no matter the application. The True View 3DIS includes all the components and software necessary to collect LIDAR and RGB image data and process these data to a 3D colorized point cloud in LAS format. True View systems use Applanix POS for best-in-class position and orientation accuracy.

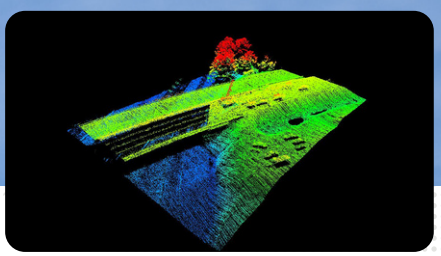
Drone LIDAR Sensor Subscription Offering

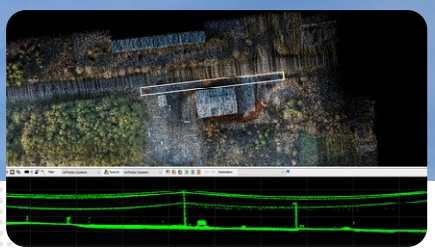
Explore drone LIDAR at low risk and low cost. This unique business model that allows customers to acquire a True View 410/515 3DIS under a subscription model for periods as short as ONE MONTH! This is an excellent model for seasonal use and surge capacity.

TrueView
GeoCue

Innovate.
Integrate.
Elevate.







3D IMAGING SENSORS

Drone LIDAR + Photogrammetry Integration

Data Collection

Collect LIDAR and Photogrammetry in a single flight. True View 3DIS can be mounted on just about any UAV platform.

Data Processing

True View EVO software is bundled with every 3DIS. EVO generates a 3D LIDAR point cloud in LAS format, colorizes the point cloud and geotags the collected images.

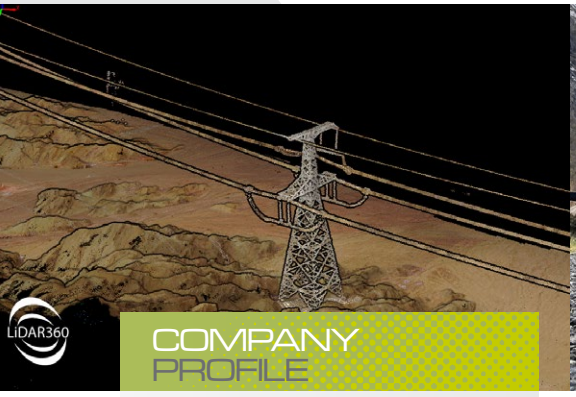
Data Management

Manage True View Points and sensor calibration files along with hosting your True View Data in our Reckon Portal.

www.geocue.com/trueview info@geocue.com

GeoCue Group

GreenValley International



APPLICATIONS

- REMOTE SENSING
- GIS
- FORESTRY
- UTILITIES
- POWERLINE INSPECTION
- MINING
- 3D MAPPING
- DIGITAL TWINS

COMPANY PROFILE

Headquartered in Berkeley, California, GreenValley International is a leading innovator of 3D mapping technologies. We provide a wide range of advanced aerial, terrestrial, and mobile LiDAR surveying and mapping hardware systems, as well as cutting-edge software and service solutions. we strive to bring to our customers the most effective products that will get the job done.

GreenValley International

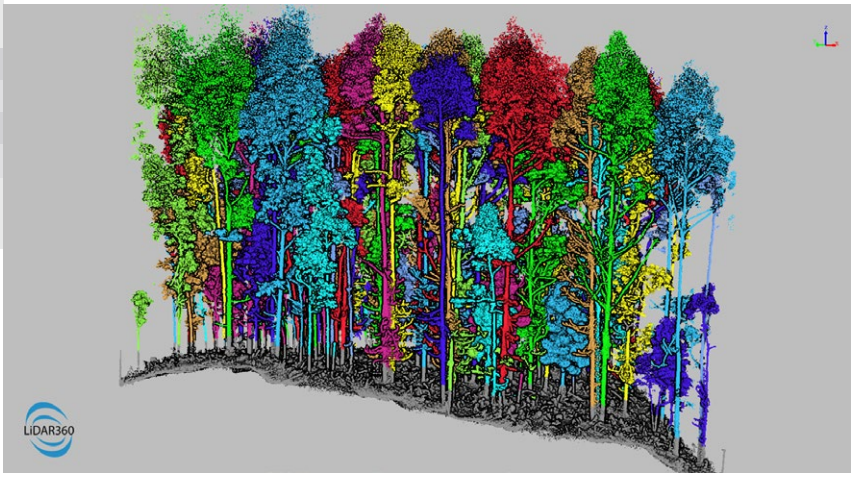
+1(510)345-2899
info@greenvalleyintl.com
2120 University Ave
Berkeley 94704, California, USA

greenvalleyintl.com

Accelerate your surveying

Our high-precision lidar scanning systems, such as LiAir (UAV/Fixed-Wing), LiMobile (vehicle-mounted), LiBackpack, and LiPod (terrestrial), help create smart cities and provide intelligent solutions in energy, agriculture, forestry, roadwork, mining, and more. GreenValley International's LiDAR360, LiPowerline, LiStreet, and other software solutions provide core processing and analysis for accurate point cloud editing and visualization.

While expanding, our primary business efforts focus on innovation and producing breakthrough technology to help create a sustainable future.



GreenValley International

LiAIR V70

Aerial 3D Mapping System

Scan Rate
240,000 pts/s

Lightweight
1 kg

Accuracy
±5 cm

Designed by Surveyors
Built for Surveyors

info@greenvallyintl.com
(510) 345-2899

RIEGL

APPLICATIONS

- AIRBORNE
- BATHYMETRIC
- MINING
- MOBILE
- INDUSTRIAL
- TERRESTRIAL
- UNMANNED
- WIDE-AREA

COMPANY PROFILE

With more than 40 years of experience in the research, development and production of laser rangefinders, distancemeters and scanners *RIEGL* delivers proven innovations in 3D.

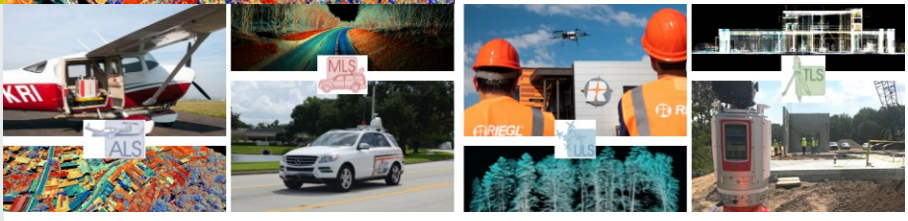
The combination of *RIEGL's* state-of-the-art hardware for terrestrial, industrial, mobile, airborne, bathymetric and UAV-based laser scanning with appropriate, equally innovative *RIEGL* software packages for data acquisition and processing results in powerful solutions for multiple fields of application in surveying.

RIEGL has always been committed to delivering the highest performance, quality, reliability, and longevity of all its products and services, and strict adherence to applicable international standards is a priority.

It is our ambition to perfectly fulfil measurement tasks fully satisfying the customers' expectations worldwide.

Founded 1977
240+ Employees
Horn, Austria
Winter Garden, FL USA

Riegl.com



Innovation in 3D

RIEGL **Terrestrial laser** scanners provide detailed and highly accurate 3D data rapidly and efficiently. Applications are wide ranging, including Topography, Construction, As-Built Surveying, Architecture, Archaeology, Monitoring, Civil Engineering and City Modelling.

Airborne laser scanning is a rapid, highly accurate and efficient method of capturing 3D data of large areas, such as agricultural or forestry sites, wide area mapping, urban areas, industrial plants, etc.

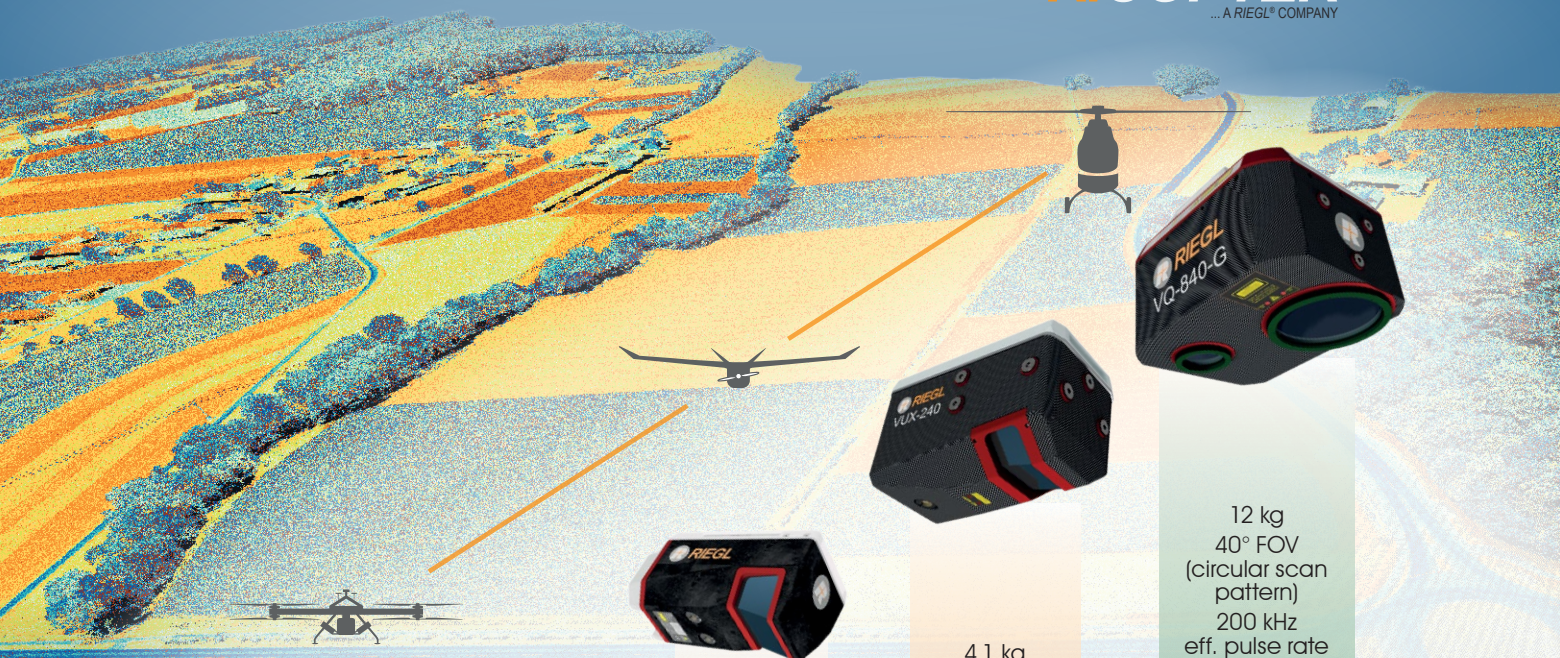
RIEGL airborne laser scanners make use of the latest state-of-the-art laser and signal processing technology. They are exceptionally compact, lightweight and cost effective, and are designed to meet the most challenging requirements in airborne surveying.

Unmanned Laser Scanning, utilizing high-end unmanned airborne platforms, provides the possibility to acquire data from dangerous and/or hard-to-reach areas, whilst offering a high cost to benefit ratio for numerous applications, for example Agricultural and Forestry, Defense, Wide Area Mapping, Flood Zone Mapping, Topography and Mining. For years, *RIEGL* Laser Scanners have been successfully used in this sector. Our current efforts in R&D guarantee to provide the user with state-of-the-art laser scanning engines of the highest quality, to meeting the specific challenges of surveying applications using advanced UAS/UAV/RPAS platforms. Furthermore, we are proud to be the first major LiDAR manufacturer to develop its own unmanned aerial system.

Both *RIEGL* 2D and 3D laser scanners are ideally suited for **mobile mapping** applications. In order to register scan data acquired from moving platforms, such as trucks, boats, trains, road and off-road vehicles, the laser scanner is supplemented by position and attitude sensors, for example GPS and IMU.

RIEGL WAVEFORM LIDAR
FOR UAV-BASED SURVEYING

DISTRIBUTED, SUPPORTED AND SERVICED BY
RiCOPTER®
... A RIEGL® COMPANY



1.6 kg
360° FOV
100 / 200 kHz
eff.pulse rate

extremely lightweight

3.5 kg
360° FOV
1.2 / 1.5 MHz
eff. pulse rate

powerful sensor for various applications in wide area UAV surveying

2.0 kg
100° FOV
1.5 MHz
eff. pulse rate

NFB (Nadir/ Forward/ Backward) Scanning for an optimal coverage of complex and vertical targets

4.1 kg
75° FOV
1.5 MHz
eff. pulse rate

versatile scanner for use on high-speed UAVs, helicopters or small manned aeroplanes

12 kg
40° FOV
(circular scan pattern)
200 kHz
eff. pulse rate
water penetration
2 Secchi depths

for topo-bathymetric LiDAR applications

efficient high resolution coastline or shallow water surveying

miniVUX-1 / 2 / 3UAV ***NEW*** miniVUX-1LR	***NEW*** VUX-1UAV[22] ***NEW*** VUX-1LR[22]	VUX-120	VUX-240	VQ-840-G
for applications using low-flying small or mid-sized multi-rotor UAVs e.g. mining, topography, forestry, landslide and avalanche monitoring		**for applications using fixed-wing UAVs** e.g. corridor mapping, city modeling	**for applications using higher-flying large UAVs or helicopters** e.g. mapping with the need of detailed high-resolution data	

Explore the full portfolio of proven RIEGL LIDAR sensors and systems
www.riegl.com

RIEGL®

SBG SYSTEMS

APPLICATIONS

- AIRBORME
- AUTOMOTIVE
- DEFENSE
- INERTIAL
- MAPPING
- MARINE
- SURVEYING
- UNMANNED

COMPANY PROFILE

SBG Systems is a fast-growing supplier of miniature, high performance and innovative motion sensing solutions. SBG Systems is headquartered in Carrières-sur-Seine, France and operates in North America from its subsidiary in Santa Anna, CA, and in Asia with its subsidiary in Singapore. SBG Systems offers a complete line of inertial sensors, such as Attitude and Heading Reference System (AHRS) or Inertial Measurement Unit (IMU), based on the state-of-the-art MEMS technology. This technology combined with advanced calibration techniques offers miniature and low-cost solutions while maintaining a very high performance at every level. Our sensors are ideal for industrial, defense & research projects such as unmanned vehicle control, antenna tracking, camera stabilization, and surveying applications. From hydrography to mobile mapping and aerial cartography, SBG Systems offers a complete solution including the IMU, PPK software and services.

SBG SYSTEMS

Founded 2007
11–50 Employees
Carrières-sur-Seine, France
Santa Ana, CA

sbg-systems.com

New Ellipse Series:

Smallest High-end INS/GNSS with Qinertia Post-Processing

SBG Systems renewed its popular line of miniature inertial sensors with high-end functionalities and RTK. The 3rd generation of the Ellipse Series benefits from a 64-bit architecture allowing high-precision signal processing. All the INS/GNSS now embed a dual-frequency, quad constellations GNSS receiver for centimetric position, and higher orientation accuracy.

New Ellipse-D: The Smallest Dual-Antenna and Dual-Frequency GNSS/INS

The Ellipse-D embeds a dual-antenna RTK GNSS, allowing heading in a few seconds, in all dynamic conditions, and even in challenging GNSS conditions. This high-end inertial sensor provides unmatched precise performance in attitude (0.05°) and heading (0.2°). All these features are made possible either in the 17-gram OEM version or the IP68 box version.

It is also compatible with SBG Systems' in-house post-processing software: Qinertia. Post-processing allows even higher accuracy for delivering more precise maps after data collection.

INS/GNSS Post-Processing for all Applications with Qinertia

This full-featured software gives access to offline RTK corrections and processes inertial and GNSS raw data to further enhance accuracy and secures the survey, thus enhancing SBG Inertial Navigation Systems' performance.

Qinertia now supports third-party IMUs and all GNSS receivers and covers all surveyors' projects with its new GNSS license to post-process both static and kinematic GNSS data.

It now includes a brand-new Virtual Base Stations (VBS) feature to ensure a maximized, homogeneous, and robust position accuracy. With its new features for UAV Photogrammetry, such as image geotagging and specific outputs, Qinertia can dramatically reduce the need of GCP and maximize ROI with an optimal workflow.

SBG SYSTEMS

0.05° ATTITUDE | **0.02°** HEADING | **1 cm** POSITION

The Smallest RTK GNSS/ INS for Robust Real-Time Navigation

NEW ELLIPSE-D

- Quad constellations and Dual-frequency
- Fusion with Pulse or CAN OBDII Odometer
- Fast Initialization

Ellipse-D
RTK Dual Antenna

Ellipse-N
RTK Single Antenna

OEM
RTK Best-in-class SWaP-C

Visit our website: **www.sbg-systems.com**

Stonex USA

APPLICATIONS

- SURVEYING
- MAPPING
- GNSS NETWORKS
- GIS
- 3D SCANNING
- MONITORING
- PRECISION FARMING
- CONSTRUCTION INSTRUMENTS

COMPANY PROFILE

STONEX is one of the world's leading companies in the production of measuring and survey instruments, with over 200 qualified distributors worldwide. The company places the maximum attention on innovation and development of solutions for surveying, precision positioning, GPS networks, and 3D Scanning. The company aims to offer a portfolio of services and products of high quality that meets every need both during the purchase phase and after-sales.

Stonex produces high-quality survey instruments and sells them all over the world thanks to its partners.

STONEX U.S.A.

Stonex USA
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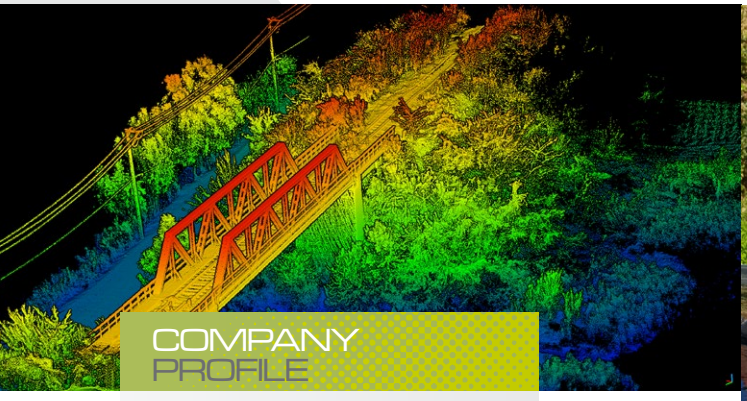

COMPANY PROFILE

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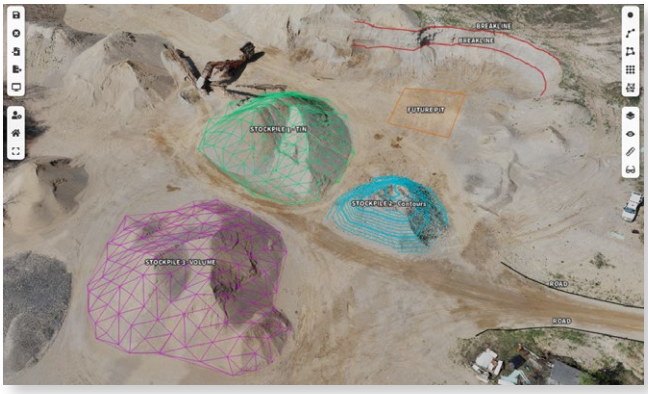

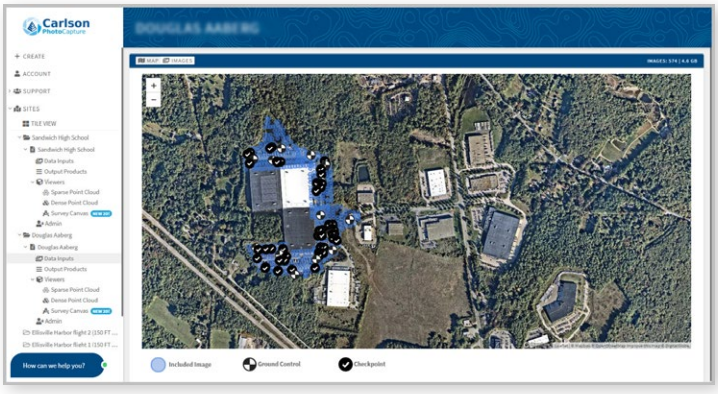

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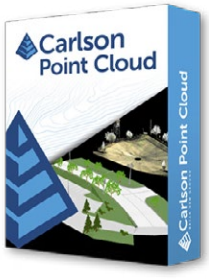

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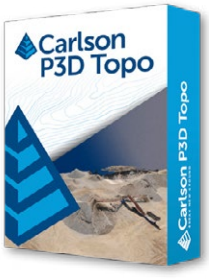

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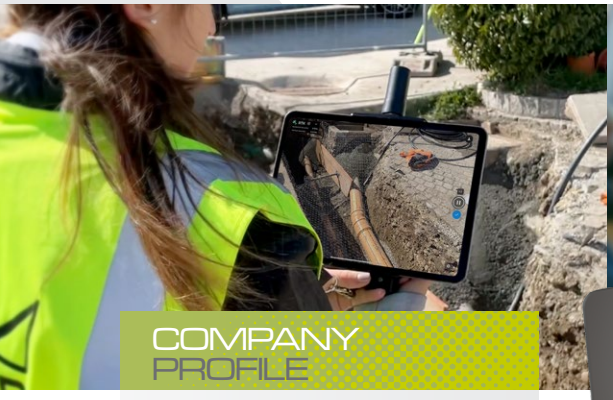

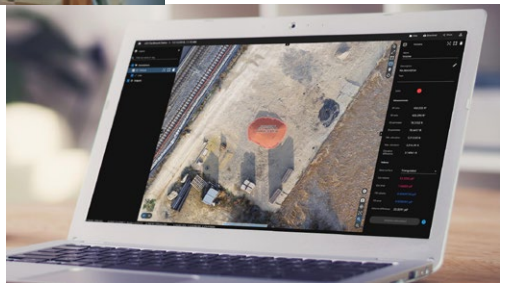

COMPANY PROFILE

Pix4D is the specialist in converting images taken by drones, aircraft, and mobile devices into georeferenced 2D orthomosaics and 3D surface models and point clouds. Pix4D uses imagery data as well as LiDAR point clouds to render results read for 3D models or CAD. Centimeter-grade results can be rendered with both aerial and terrestrial data. Consumer and specialist drones are both supported by Pix4D products, delivering survey-grade accuracy for the next generation of mapping. Assess, edit, and improve your projects directly in Pix4D software using the rayCloud, Mosaic Editor, and seamlessly import your results into any professional GIS, CAD, and traditional photogrammetry software package.

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Pix4D provides 14 software and hardware solutions that give professionals the power to measure, analyze, and model from images captured by drone, hand, or plane. The ecosystem of products encompasses everything from data collection to creating CAD-ready outputs. They serve a variety of industries, including surveying, public safety, agriculture, construction, and telecommunications. Specific products are designed with specific applications, such as PIX4Dscan and PIX4Dinspect being tailor-made with AI for telecom, whilst others (eg PIX4Dcloud) can be used across industries.

The solutions powered by Pix4D are used worldwide by tens of thousands of professionals. The original Pix4D software, PIX4Dmapper, is referred to as the “Swiss-army knife” of photogrammetry, packed with features that make it a world-leading product. It can generate 2D orthomosaics, 3D models, and multi-spectral image analysis. However, the new products being developed offer great excitement, including PIX4Dmatic - capable of crunching over 10,000 images in a single dataset - and PIX4Dsurvey, which automates vectorizing processes and prepares data for CAD. PIX4Dfields is the go-to photogrammetry solution for agriculture, able to generate multi-spectral maps for year-round crop management.

The handheld solutions by Pix4D bring even more opportunities. The PIX4Dcatch app takes advantage of LiDAR sensors in modern phones and tablets, and when paired with the viDoc RTK rover (giving geo-locational accuracy of 5 cm to iPhones and iPads), the two empower single-point measurement and RTK-accurate 3D models from images collected with everyday mobile devices. The entire suite of Pix4D products is intuitive and user-friendly, with cloud-based options, designed to move seamlessly from data collection to client-ready presentation.

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Winning with UAV-Lidar by Acquisition and Subject Matter Expertise

NV5 well positioned for success

A new venture is formed ...

Many business travelers must have wondered how to manage the return to normality as covid receded[1]. My resumption was pleasantly gentle and local—a regular contributor to *LIDAR Magazine*, Mark Meade, who is based in Lexington, Kentucky and is senior vice president shared services, NV5 Geospatial, invited me to an NV5 office only four miles from my home. This office, in the northern suburbs of San Diego, houses NV5's Unmanned Systems group ("USys"), managed by Mike Stys, senior vice president of geomatics and unmanned systems. Much of the capability, and numerous staff members, had been parachuted into NV5 as a result of the acquisition in December 2017 of Skyscene, a UAV services startup in San Diego. NV5 Geospatial is the name for yet another acquisition—the geospatial and data analytics conglomerate Quantum Spatial, acquired in December 2019.

Figure 1: Example from the NV5 UAV fleet: BFD Systems SE8 heavy-lift, long-endurance octocopter.

Mark mentioned Geodyamics, purchased in March 2021 to strengthen NV5's deep-water portfolio, "They have significant capabilities, and their professionals are great to work with." Mike said that there had already been several interactions between his group and Chris Freeman of Geodynamics. NV5 had purposely named his team "Unmanned Systems", because, in the future, unmanned vehicles will go beyond aerial. "We have a USV[2] in place. Space, air, land and sea, we'll do it all and we're looking at one for mining, to go into caverns and canyons. We'll solve the technical challenges."

The company has come a long way from the DJI Inspire and RIEGL lidar sensor they started with. NV5 quickly invested in a more robust platform along with a RIEGL VUX-1 lidar sensor. The team then built a group of dedicated professionals and subject matter experts who quickly integrated sensors on the DJI M600 platform. Within months, they were producing engineering-grade orthomosaics and lidar point clouds to use at NV5. The fleet of UAV platforms and sensors continues to expand and includes American-made UAVs

1 This was drafted before omicron.

2 Unmanned surface vehicle or unmanned surface vessel, i.e. travels autonomously on water surface.

BY A. STEWART **WALKER**

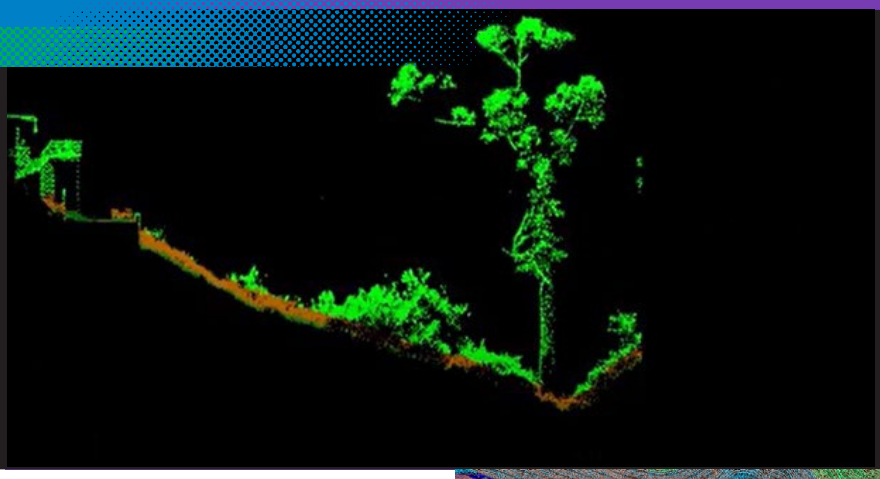


Figure 2: Cross-section through a dense lidar dataset. Note the bare earth surface and considerable vegetation.

(**Figure 1**), multiple lidar sensors, and thermal and multispectral cameras. Mike emphasized, "The strength of this team is its understanding of survey and engineering first, then UAV operations second".

Indeed, the group is considering expanding its topobathymetric capabilities. Though impressed with the penetration, point density and accuracy of the ASTRALite EDGE sensor[3], the team was concerned that its low flying height could compromise coverage, so they're looking up market, at the RIEGL VQ-840-G. This weighs about 15 kg (33 lb) with GNSS and IMU, however, so it doesn't fly on a small UAV. Some UAVs can cope with such payloads, such as RIEGL's own RiCOPTER-M, but the regulatory environment becomes more complex for UAVs above 55 lb.

Mark interjected that NV5 Geospatial had just completed a test of the VQ-840-G with RIEGL and GEO1. Ron Chapple[4], GEO1's CEO, provided a helicopter; NV5 Geospatial, the sensor operator and the processing; and RIEGL, the VQ-840-G. The test site was Morro Bay, California. Results are imminent and Mark hinted that early indications were very promising.

3 Learn more at https://lidarmag.com/2021/04/01/setting-a-new-standard-for-topobathymetric-surveys/.

4 Ron Chapple is a contributor to *LIDAR Magazine*: https://lidarmag.com/2020/06/14/thought-leader-a-billion-points-of-light/.

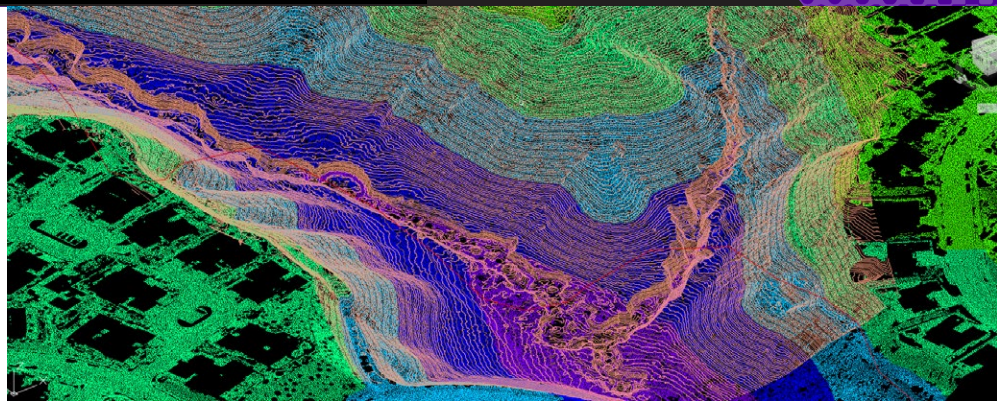


Figure 3: Digital elevation model generated without boots on the ground, which would have disturbed vegetation and provided challenges for navigating steep slopes.

... with talented, energetic people ...

Mainly, this is a story about people. Also present for my visit were Melissa Christie, a NV5 geospatial account manager based in the Bay Area, and Kurt Kathol, UAV account manager. Joining remotely from Fredericton, New Brunswick, Canada, was Lukas Fraser, lidar specialist and engineer-in-training.

Mike, a Michigan State and Ohio State graduate, entered the geospatial profession after graduating in 1991 and worked initially in GIS, then began to work with terrestrial laser scanning (TLS) in 2000-01, always in the AEC space. At one point he purchased a VZ-420 from Ted Knaak, who at that time was president of RIEGL USA. Mike, who is also a member of ASPRS, reached his current position through NV5's acquisition of WHPacific in 2019, after which NV5 asked him to take the lead on the company's geospatial team. But things changed with the purchase of Quantum Spatial a few months later—the geospatial team grew a tad! His operation, therefore, became focused on unmanned systems and the team is now 22 strong, of whom five are key pilots, lidar-trained and ortho-trained. Born and raised in Michigan, Mike came to California eight years ago. His WHPacific role had expanded to running multiple offices across the western US, so he has been pleased that his current assignment is more focused.

The early part of the story has been reported elsewhere[5]. Kurt started out with drones, working for the Department of Homeland Security, US Customs and Border Protection, on surveillance of the southern border, then

5 Roe, G., 2019. NV5 provides integrated UAV lidar mapping services, *LidarNews*, 17 May 2019.

Figure 4: Dataset created from the fusion of sonar and aerial lidar.

co-founded Skyscene with Matt O'Brien, who came from the construction industry. After Skyscene was acquired, Matt and Kurt occupied management positions within NV5.

Mike added, "We have the luxury of Kurt playing a role where he's obviously got the technical capabilities and knowledge, but he's also our account manager, because he does a wonderful job selling our services. So, he's migrated out of operations and more into business development."

Melissa worked for USGS Water Resources Division in Carson City, Nevada, National Park Service in San Francisco, and, since 2004, in private industry, when she moved to HJW Geospatial, which was acquired by Photo Science in 2010. The latter became Quantum Spatial in 2013. Some readers will remember that HJW moved from its facility near Oakland Airport to downtown Oakland, where it occupied what had been a department store, all the more appropriate since it was briefly under the ownership of Harrods, the famous Knightsbridge emporium in London, UK. Mark quipped, "There were no synergies with Harrods—zero!" Harrods' boss Mohamed Al-Fayed sent a representative to Oakland periodically, who could not fathom what went on, lots of people on workstations in dark rooms, looking at photos and clicking on points and lines.

Melissa has been an ASPRS member since 2000 and is in her fifth year as secretary/treasurer of the Pacific Southwest Region. Though she works in all the western states, her focus lately has been on California. She was enthusiastic, "Mark's been so great to help me work through all the opportunities in California, including the Unmanned Systems group. Speaking of synergy—we're already experiencing cross-pollination, working with each other and bringing jobs from all over." She felt that the NV5 Geospatial strategy had been to let the UAV services market mature and this has happened. When she approaches clients or they approach her by saying that they have a small site, don't want to go overboard, and want to understand what their options are, she can now answer that NV5 can collect a project, with high accuracy and high precision and certain cost efficiencies. "I think that it's a wonderful synergy because we can sell this, we can talk about it with confidence. Also, the approach to selling UAV-lidar services by a surveying and mapping company is intriguing, because it's not the same as with the projects they've been selling until now, i.e. big projects with manned aircraft," Melissa explained. "It's not a different world, but it has its peculiarities".

Mike envisions a tremendous amount of additional opportunity, "Fortunately we have a few thousand clients right under our nose here, with NV5—we're a multidisciplinary, worldwide company."

Mark was animated, "Synergies are really good! It's probably one of the more aggressive initiatives at NV5."

Lukas joined the conversation from Canada. He attended the University of New Brunswick for a geomatics engineering degree, then started working in the remote sensing industry, with Leading Edge Geomatics in Fredericton, New Brunswick. He concentrated on lidar processing, soaking up knowledge. "I got to oversee some really cool data sets. All of Puerto Rico, for example, I processed that. I traveled to Nantucket and Martha's Vineyard, for the topobathy acquisition. I also had large projects in Texas and Virginia. We collected data for the whole provinces of New Brunswick and Nova Scotia. I was really focused on finding ways to process these enormous datasets as fast as possible, perform quality control of these huge areas, because, with enormous datasets, you can't look through every square inch—I wanted to automate quality control and basically make sure that the results are good enough to be

published, whether it's through Natural Resources Canada or USGS."

Kurt reached out to Lukas while the ink on the Skyscene acquisition was still wet. "Kurt messaged me on LinkedIn on Christmas Day. I thought he was probably a scam! He just ran a search on LinkedIn and my profile popped up. I had a very specific set of skills, I guess you could say." Lukas was quickly added to the team. He was tasked to find a way to process the high-quality US data sets and turn them around efficiently, but not sacrifice any of the accuracy, or any of the quality control measures, such as the USGS *Lidar Base Specification* or the *ASPRS Accuracy Standards for Digital Geospatial Data*. Lukas ensures that NV5's data sets meet clients' accuracy requirements. His work has expanded, however, into making Civil 3D drawings, for example, or setting up services for clients in web browsers. Lukas summed it up, "Getting accurate point clouds is great, yet most people hate point clouds, clients don't want to see them, they don't want to interact with these huge data sets. So we need to make a product that people can use and provide value to our customers. We even touch the BIM world."

Lukas currently works remotely and is looking to hire. Mike added, "There's the University across the street, and he's got the green light to go find more talent."

Kurt, it turns out, is an ace recruiter. Mike elaborated, "Kurt has a sixth sense. One of our best mapping technicians was at a coffee house and Kurt started talking to him. He gave his background, Kurt offered him a job on the spot, and he's one of our top producers."

Kurt added that he had run the hiring of Lukas by NV5 Geospatial lidar whizz Andres Vargas. Kurt had been friends with Andres when they were with Skyscene and RIEGL USA respectively. The three had a teleconference and Andres opined on Lukas, "This guy's the real deal."

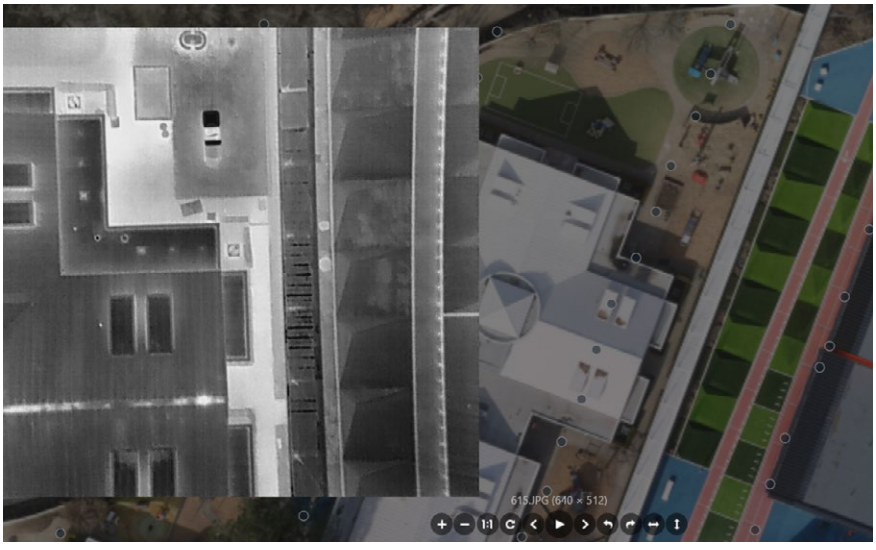


Figure 5: Combining orthomosaics and thermal imagery to identify anomalies in structures.

... who can run successful projects ...

NV5 showcased several UAV-lidar projects for me.

Plaintiff vs. defendant—fence dispute

The first was set in La Jolla, a coastal suburb of San Diego (**Figure 2**). Lukas explained that it was one of the group's smaller projects. The motivation was one resident suing another for building a spike fence that blocked his view of the ocean. The yard was filled with dense vegetation. But it was possible to use the laser scanner to see down to the ground to create a satisfactory profile of the backyard, find the lowest point and measure from it to the top of the spike fence to prove that it was illegal—it was too tall. The UAV-lidar approach was very successful—Lukas described it, "We're in between helicopters and planes and mobile. Obviously, we don't quite have the same level of detail, but it's enough for us to go in and map out her retaining walls and a lot of other features in 3D that were traditionally acquired through mobile, or photogrammetry. For example, we're getting a really great definition on linear features, enough to do all that extraction. And once again, TopoDOT provides a semi-automated way of skipping through these data sets, getting all the break-lines and profiles." The sensor was from the RIEGL VUX family.

Major southern California utility—pure water project

Lukas moved to a larger project, also in La Jolla, executed for the City of San Diego (**Figure 3**). Again there were problems with very dense vegetation. The customer needed to see where all the drainage locations were. They had a DJI Phantom 4 and had flown it there, but couldn't really acquire images through the vegetation and couldn't

Figure 6: Dataset that combines UAV and terrestrial lidar for high-fidelity model creation.

build an ortho. They considered sending a crew in to look at it, but it was too dense, it wasn't safe, and they were worried about hazards. They thought, however, that they knew a couple of locations where the water was draining. Therefore NV5 collected very high-density lidar and was able not only to verify the locations but even identify a few more that couldn't be seen from the Phantom 4 photography. The customer was delighted with the lidar-derived data set, with enough detail to highlight exactly where the water was.

Ventura River diversion and leak repair

Mike put the next project (**Figure 4**) in context: "UAV-lidar we do every day, we shoot down to the ground, we do it very well. A remotely operated sonar is something for which we've rented boats from time to time, but we're really hoping to do more of these projects, because you can really see the added value of being able to collect topographic, and also the underwater elevation information for the project." He was keen to win projects of which NV5 was well capable, but would perhaps hit challenges with topobathymetric lidar, perhaps for cost reasons or just water that's too murky. So for this dataset NV5 merged lidar and sonar to create accurate data above and below water. The result is a seamless data set, with contours that flow from the ground to the bottom of the pond. The accuracy is slightly reduced with sonar, but is sufficient for many applications. The coverage of the site was complete. NV5 was able to estimate what would be required if the customer had to fill in the reservoir.

Company views campus as-builts and thermals in portal

The next example, the campus of a well-known company, was chosen to emphasize that getting the data into the client's hands is so important that NV5 makes special efforts to come up with the right tool. This is a differentiator—it's not sufficient just to excel at collecting data and checking that it's precise and accurate. What happens next? Unmanned Systems enjoys the luxury of working for the larger NV5, so is exposed to field engineers, construction managers, people in the field making their clients happy. They receive "tribal" knowledge of what is expected and how to develop a usable tool. Lukas showed the result, a web-based portal developed in-house. Lukas likened the portal experience to broadening the audience among the client's personnel. This opens up the use of the data and the client receives greater value. It's intriguing to see how the data gets used. Melissa commented, "You want it to become easier, more user friendly—and in doing so even more people can get involved."

Lukas sketched the development of the portal. They worked first with a group internally, then incorporated feedback from clients. People are interested, but they can't interact with these big datasets. For the campus project, they put all the Civil 3D data and AutoCAD drawings on the web so anyone can log in, take a look and manipulate the datasets. Layers can be turned on and off. The viewer can make distance measurements. Tools are being added continually, not just for measurements—there's also a legend function. There are similarities to GIS software used by professionals, but the customer experience is much easier and people believe that they can do it. It's possible to accomplish, in a web browser, anything that could be done with a point cloud in a normal GIS browser. Points can be classified. The user can choose what to see—intensity, elevation, class, etc. Cross-sections can be measured and downloaded as csv files.

Interestingly, one of the requirements for this project was thermal imagery, over and above lidar and conventional

Figure 7: Survey mark-outs can be safely collected from unmanned imagery, increasing safety and eliminating interruptions to traffic flow.

orthos. The team made a thermal viewer, so the customer could look at individual images and buildings. They worked on temperature gradients based on the values in the images. It's easy to spot on a building an anomaly that should be investigated (**Figure 5**).

Architectural preservation in Florida

Lukas moved on to a recent project in Palm Beach, a hotel that a developer was hoping to convert into a brand new, five-star hotel (**Figure 6**). Although only walls and cement floors remained, the client wanted to preserve as much of the original architecture as possible but wasn't sure how much damage would be done by renovation. NV5 draped the image across the point cloud. Traditionally, BIM modeling has been based on terrestrial lidar, but a project like this is demanding—relative accuracy has to be really high, everything has to fit together really well, so tremendous detail is necessary for the modeling. NV5 did terrestrial lidar, therefore, then flew multiple passes at different elevations with a UAV and merged the airborne and terrestrial data. They admitted to some overkill, but the result was excellent, and they were able to create a model from it. Great satisfaction was derived from helping to preserve a historic building.

Mike noted that the client had been internal—a geotechnical group from an NV5 office in Florida, "people who go in and do everything with buildings"—so this ties back to the synergies mentioned earlier. Melissa thought that this sort of model could be used for real estate. A view of the ocean increases the price of a condo. Mike answered in a slightly different vein, "Let's say we fly a dense area with considerable industrial activity to update the model with all the key components, e.g. propane tanks and shutoff valves. Terrestrial, UAV, mobile, you put them all together, you can model the update quicker. We're getting into the emergency response world."

Making GIS and utilities fit

Lukas warmed to the theme of "fitting things together" and discussed orthorectified imagery. Lidar and imagery are collected independently, so Unmanned Systems do two separate flights, which takes a little more time, but are working on different solutions to fitting the imagery and lidar together. On top of control points and independent check points, this gives an additional independent check, so Unmanned Systems can compare lidar and imagery to ensure they are lining up perfectly. Lukas showed an example with underground utilities (**Figure 7**). The positions had been painted by the field crews, so that they avoided going into the middle of the road with total station and GNSS. They fly low with large numbers of overlapping images, so it is even possible to see underneath the vehicles for markings. They paint them as they locate them, i.e. the GIS is typically good to 10-20´, but the locator to a few inches.

Mark put this in perspective. It is a huge challenge to locate things below ground. Fifty or sixty years ago many clients didn't know the location of their assets within 500´. NV5 has encountered instances of large 48-60 inch underground pipelines where a vegetation corridor was being mowed and vegetation management performed in a right of way that was different from where the lines were located! One of the firm's most fascinating projects was in

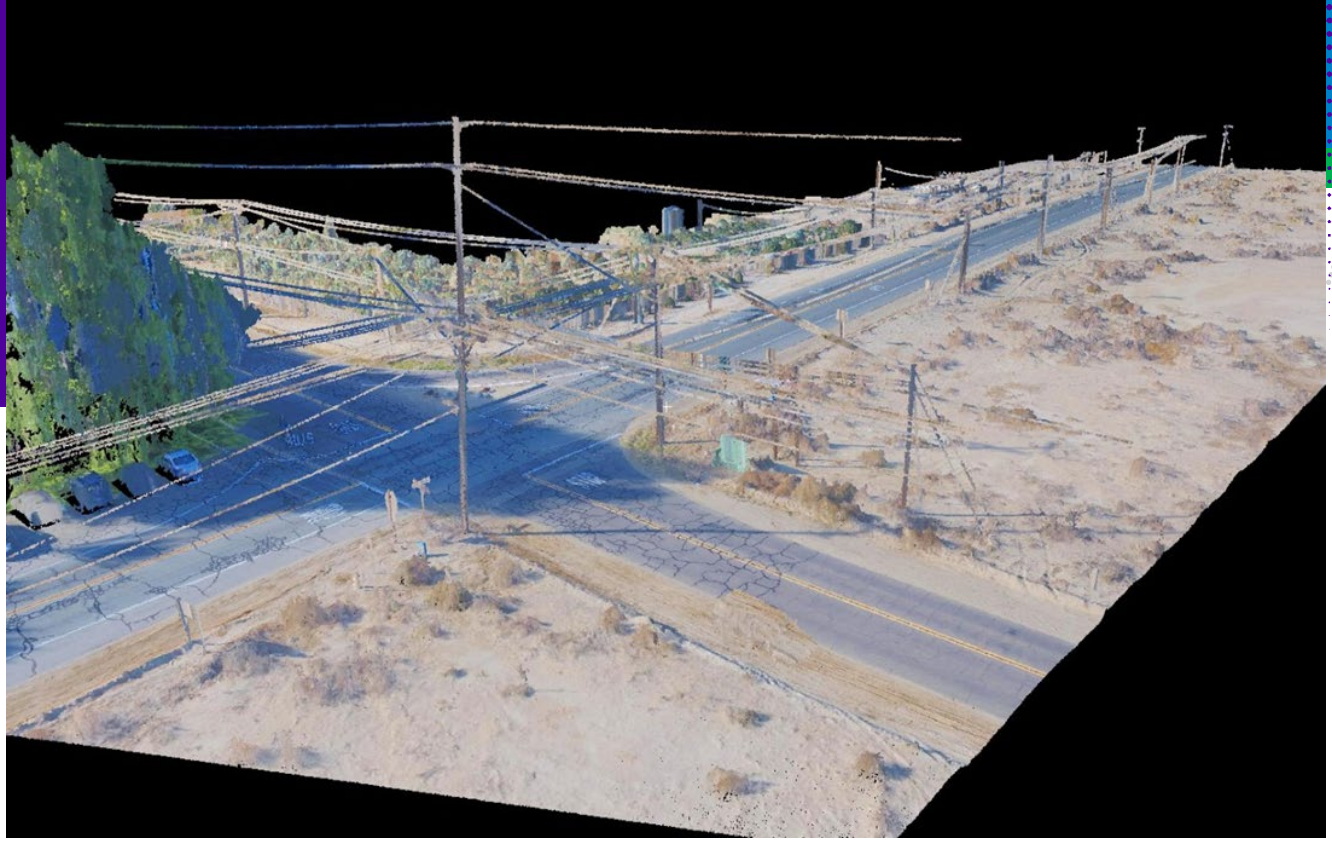


Figure 8: Lidar and imagery captured for both engineering and electrical design purposes.

the southeast 24 years ago, involving gas pipelines from the Gulf. Mark explained, "We flew their pipelines and we found a four-week window during cold weather where you could clearly see the pipelines in normal black and white imagery. This evidence was from the warming of the lines from the pump stations located frequently along the lines. The pumping warmed the lines, resulting in healthy vegetation right over the lines, giving us near perfect locations of their underground infrastructure. We used this information to update their GIS and captured GNSS-based ground truthing in the field. The locations confirmed the new locations. Moreover, features in their GIS made perfect sense. Their encasement pipes fit perfectly under roads, their river weights[6] fit under rivers and other bodies of water, and their digital twin took on significant added value."

6 Natural gas pipelines have concrete added so they don't "float" from their river crossing.

Electrical detail

Mike moved us on to the last example (a major US Air Force Base: **Figure 8**), in the utility space, one of the largest sectors in which Unmanned Systems is involved. "The great thing with UAV-lidar is that you can mobilize quickly to fit in with construction. We were flying so low with the RIEGL VUX-1LR that we got great detail not only on transmission lines but on distribution lines and service lines, even guy wires running down to the ground. Also, we were getting such high accuracy and level of detail on the ground that it saved considerable time back in the field." He explained that this provided additional detail and reduced guesswork, because numerous features have to be identified in utility mapping and there are many features on each pole, so lidar reduces the guesswork. Unmanned Systems had received considerable feedback, especially internally from NV5 engineers who have been working in this space for a long time, and have used lidar from different sources, so really appreciate knowing that nothing's going to be missed. Mike confirmed, "It's good having experienced engineers in-house to talk to, who can look at Unmanned Systems' work."

Mike pointed out that all the features were classified. "Every client has their own preference as to features they want to see classified, but there are similarities between them and standards in the industry. Every utility has different requirements, but all the required features are classified." Lukas added that Unmanned Systems was going to use the model in PLS-CADD (design software for overhead power lines), in which it was possible to try different loading conditions, different weather etc. Unmanned Systems collects weather at the time of flight. Using the data model, they can estimate what's going to happen to the wire, how it's going to sag under different loads, and how poles will be affected by adding a new pole down the line. They could export to PLS-CADD and figure out how the whole network was going to react. Unmanned Systems, therefore, take it up to a certain point, then hand it off to NV5 engineers, who can edit

and do the rest of the work. They use the model started by Unmanned Systems for their final calculations. Mike summed up, "We deliver geographically/geodetically correct placement of all the assets, saved according to the weather at that time, and hand it off down the hall. They turn it into a design and construction package. Then we fly again later and do as-builts."

And remember ground control!

Unmanned Systems always uses ground control points (GCPs). Mike said that transects, i.e. control points spread across the ground or walls of structures, are key and that his group is "well qualified when it comes to controlling lidar with UAVs." He confirmed what many of us fear, "A lot of folks don't understand that you can't just strap an expensive lidar sensor on a UAV and everything is good to go. When I was training, I used a very simple way of thinking about control—think of pinning a sheet to the ceiling."

Lukas's perception was that the UAV industry earned a bad reputation early on for statements that GCPs were unnecessary and ridiculous claims such as centimeter or sub-centimeter absolute accuracy without control. Slowly, people started to set GCPs, but they would deliver RMS reports using the same points that they had used to control the imagery, i.e. re-use GCPs as independent check points. He pontificated, "You can't do that. We took the approach that using UAVs isn't different from using helicopters or planes. We still have to talk about accuracies and requirements, for example for QL1 or QL2 lidar. For terrestrial lidar, we do the transects. Relative accuracy has been questionable in the industry, especially early on. People would get their calculations of absolute accuracy correct, but for relative accuracy the estimates were so bad that the data wasn't really useful. You should do some raster-based relative accuracy tests and statistical analysis on that, making sure that everything follows a normal distribution. Then, for density, again raster-based, make sure that 95% of the grid falls into the promised density range. These are not always used within the industry, but we've been using them for a long time. We wanted to take those things and apply them so that customers see the same reports and statistics regardless of platform. We wanted to be respected—and there are a lot of surveyors in this office, who look over our data with a fine-tooth comb! They wouldn't let us get away with anything."

Synergy is key ...

Mark took me downstairs to meet Scott Kvandal, NV5's chief synergy officer (**Figure 9**). NV5 is a large company and has completed multiple acquisitions, so having an office to manage this synergy is key. Mark's description was fulsome, "Scott is a really nice guy, really bright guy. He runs our synergy office. Remember that we are a little over 4000 employees strong." Indeed. Scott obtained such high grades in his BS at San Diego State University that he won a full ride to Stanford for an MS in environmental engineering. He's a professional engineer and has mixed a successful business career with missionary work in Paraguay. Mark met him at the interview prior to the acquisition of Quantum Spatial, when NV5 was conducting its due diligence. Scott covers synergies all across NV5, not just for NV5 Geospatial. He also runs NV5's energy group. He summarized his role, "It's just a matter of getting 45 or so acquisitions integrated and cross-selling. We've done pretty well but we can always do more, that's for sure."

Figure 9: Scott Kvandal serves as NV5's chief synergy officer.

... to building the future

NV5 is successful through both organic growth and multiple wise acquisitions. NV5's Unmanned Systems group will play a growing role in the world of UAV-lidar, using the tool when and where it's most suitable for a project, either on its own or in harness with TLS, MMS and airborne lidar from helicopters or manned aircraft. It will expand its autonomous lidar systems to surface vessels and robots on land. The dovetailing of Unmanned Systems and NV5 Geospatial into the overall NV5 operation reflects the company's consciousness of and attention to synergies. The mission to maximize the value of acquisitions will be seen with Geodynamics very soon and others in the future[7].

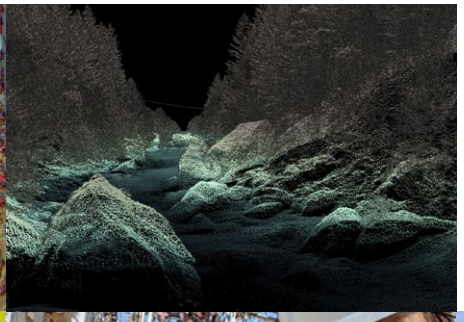
Stewart Walker is the Managing Editor of the magazine. He holds MA, MScE and PhD degrees in geography and geomatics from the universities of Glasgow, New Brunswick and Bristol, and an MBA from Heriot-Watt. He is an ASPRS-certified photogrammetrist.

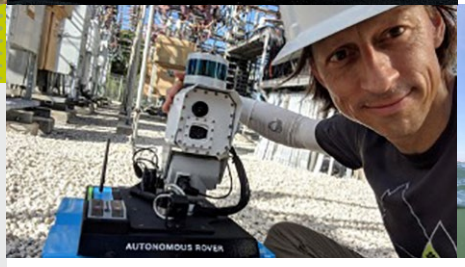
7 The pace has not let up: shortly after the visit, NV5 acquired PES Environmental.

NV5 Geospatial

APPLICATIONS

- ACQUISITION
- DATA & IMAGE PROCESSING
- ANALYTICS
- APPLICATIONS
- DATABASE MANAGEMENT





COMPANY PROFILE

NV5 Geospatial is the geospatial pioneer pushing the boundaries of data and analytics to deliver actionable intelligence to those who need to map, model, and manage their world. We lead the nation as the only end-to-end geospatial solutions provider with the capability to deliver the highest quality data and geographic insights.

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Our geospatial services have strategic value in countless applications from habitat assessment and land use planning to regulatory compliance, engineering design, and disaster preparedness. We've successfully delivered well over one million square miles of geospatial data to support projects for federal, state, tribal, private, and non-governmental organizations.

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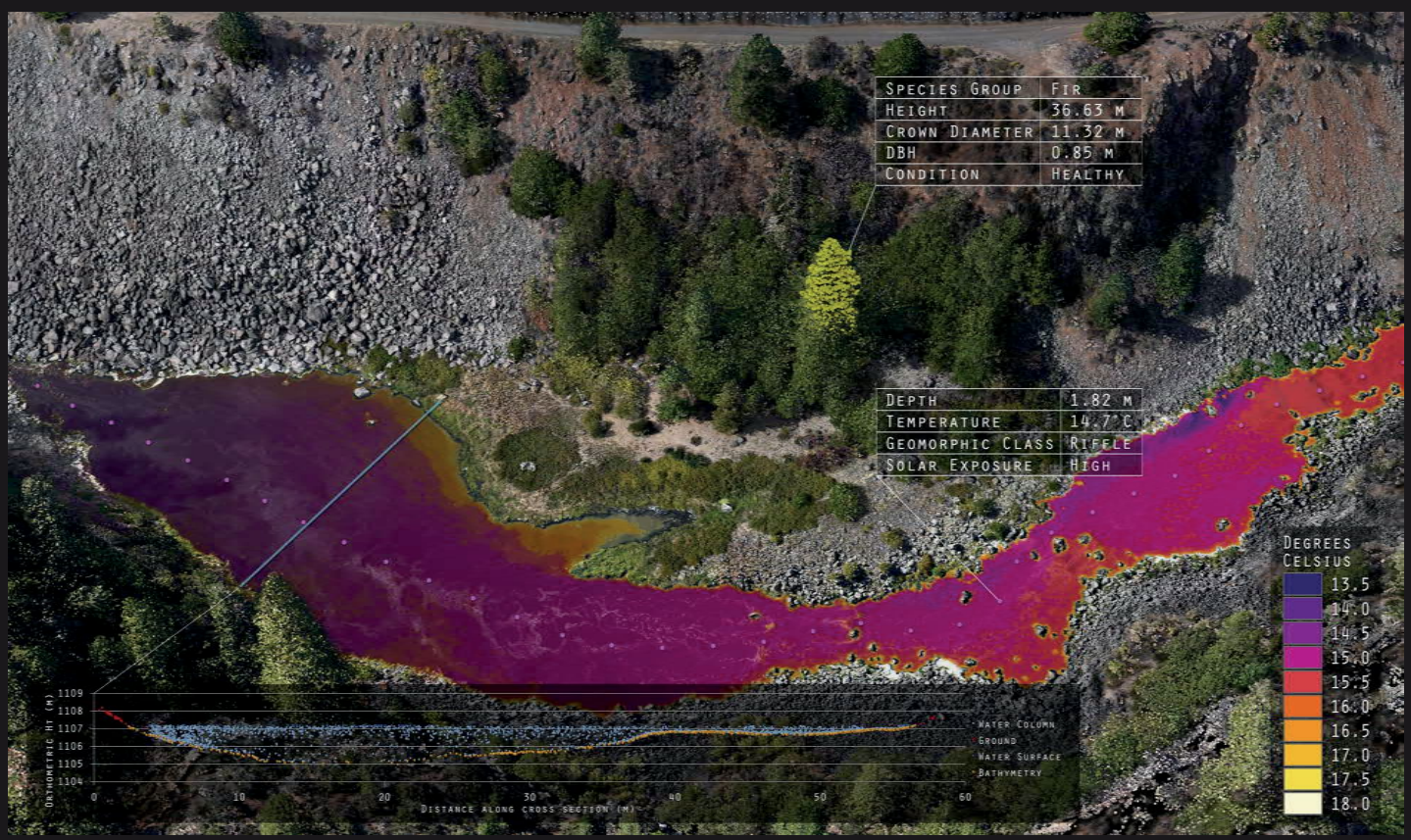

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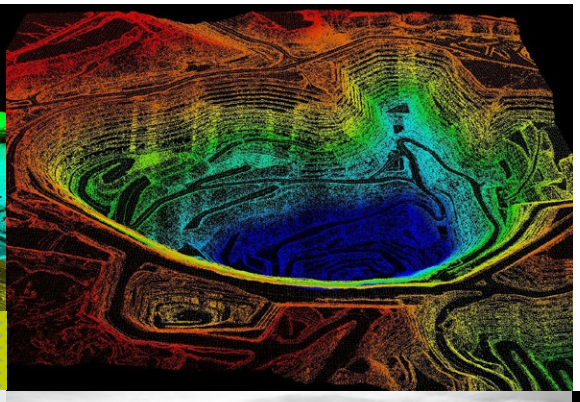

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APPLICATIONS

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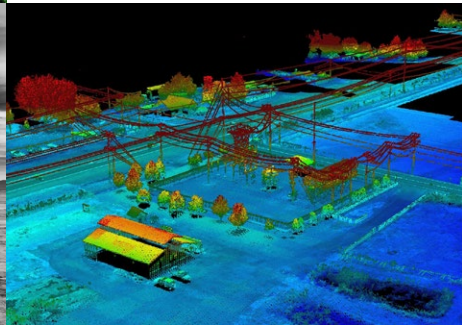
- LIDAR
- INFRASTRUCTURE
- ENERGY
- AEC
- TRANSPORTATION



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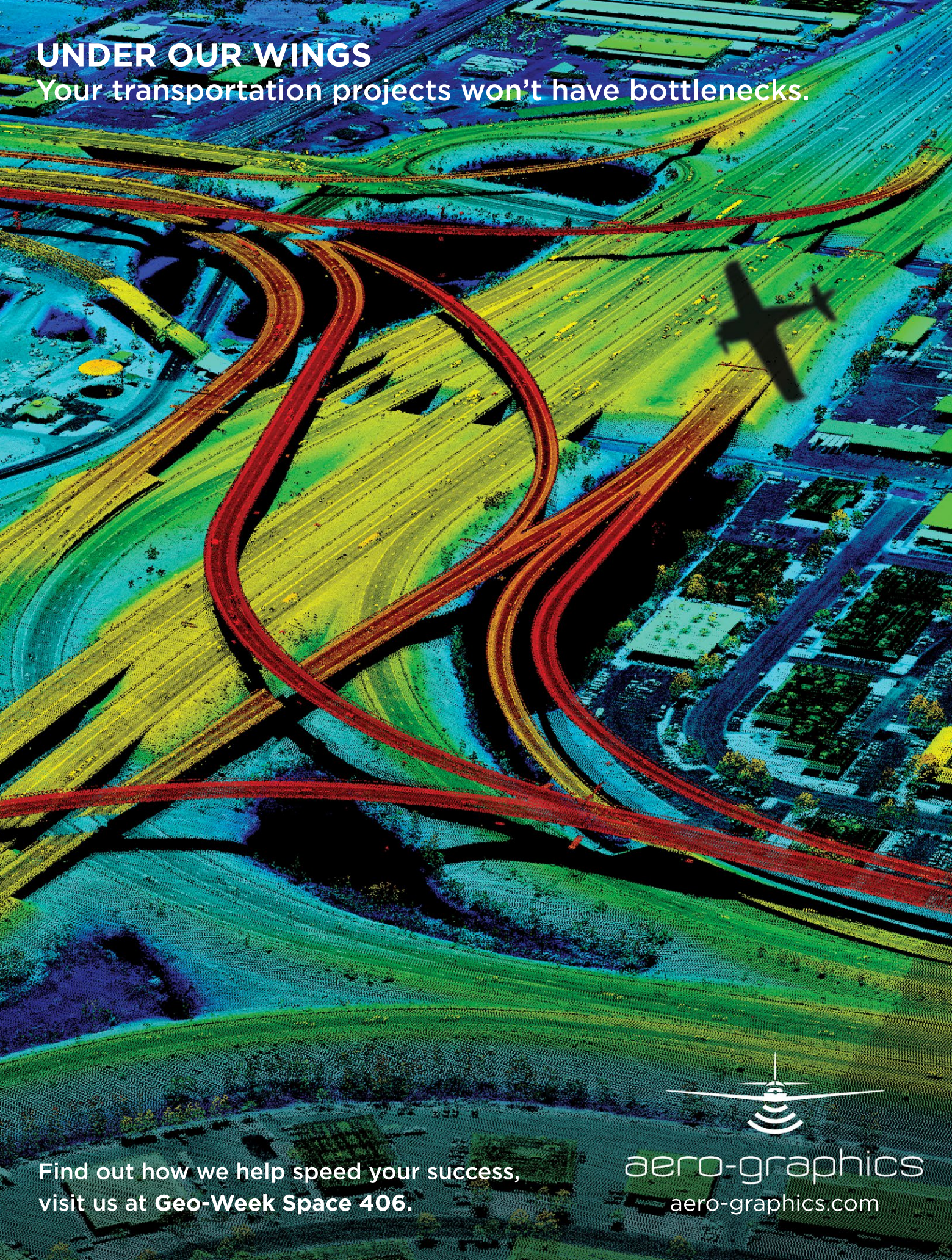
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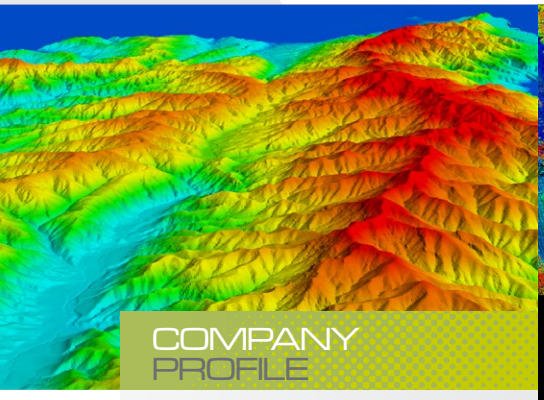

COMPANY PROFILE

Dewberry is a leading, market-facing firm with a proven history of providing professional services to public- and private-sector clients. Established in 1956 and headquartered in Fairfax, Virginia, our professionals are dedicated to solving clients' most complex challenges and transforming their communities. The firm harnesses the power of geospatial science to offer complete end-to-end remote sensing and mapping services starting with state-of-the-art airborne lidar sensors to automated processing, surveying, web/mobile GIS, and advanced data analytics. Dewberry creates, analyzes, and builds geospatial data and tools, to help clients integrate, share, and simplify the use of information allowing for more effective and efficient decision making. To learn more, visit www.dewberry.com.

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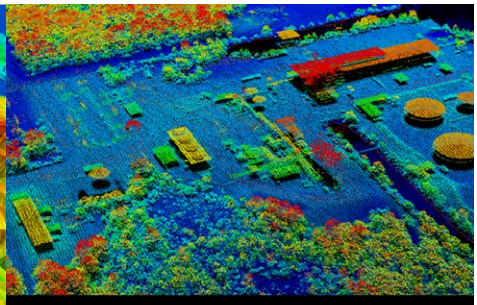
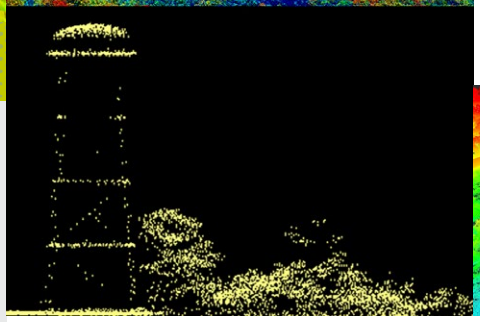
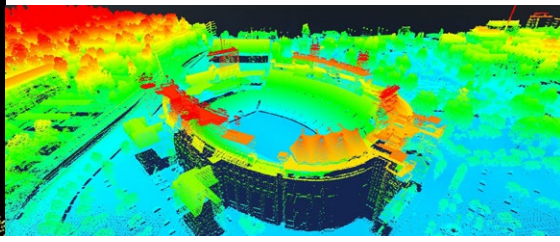




APPLICATIONS

- REMOTE SENSING
- TOPOGRAPHIC LIDAR
- TOPOBATHYMETRIC LIDAR
- GIS
- APPLICATION DEVELOPMENT
- MODELING
- ASSET MANAGEMENT
- ANALYTICS



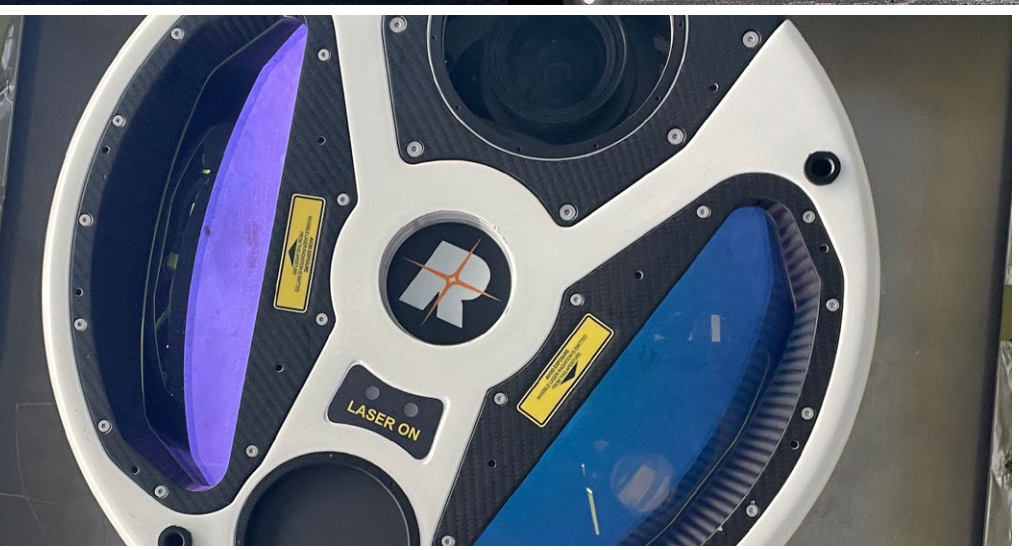
Dewberry's Geospatial and Technology Services

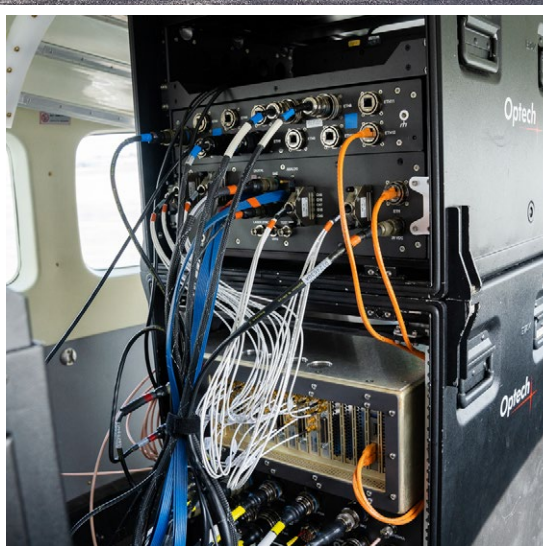
Dewberry's geospatial and technology services team creates, analyzes, and builds tools to share geospatial data, and helps clients integrate these tools into their daily lives. By fusing multiple data sets together, Dewberry provides clients with easy-to-use tools that simplify the use of information to allow for more effective and efficient decision making.

Dewberry recently purchased two sensors—the RIEGL VQ-1560 IIS topographic airborne lidar sensor and the CZMIL SuperNova, a powerful topobathymetric mapping sensor. This investment allows Dewberry to expand its mapping capabilities with current clients, keep the entire acquisition lifecycle in-house, and monitor the quality of its products. The firm is excited to empower their clients with access to the most innovative technology to meet their topographic/lidar needs, delivering hi-definition lidar datasets quickly and efficiently.

The firm's solid performance processes in geospatial technologies and corporate IT services led to it being appraised at Level 3 of the CMMI Institute's Capability Maturity Model Integration (CMMI) in Services and Development Models. In 2020, Dewberry also received the International Lidar Mapping Forum (ILMF) and Lidar Magazine's 2020 Outstanding Enterprise Achievement in Lidar award.

Dewberry works seamlessly to provide geospatial mapping and technology services across various market segments. With more than 30 years' experience, the firm is dedicated to understanding and applying the latest tools, trends, and technologies. Dewberry employs the latest GIS software and database platforms, including the full suite of ESRI products. The firm's products and services include application, web, and cloud-based development; system integration; database design mapping; data fusion; and mobile solutions.





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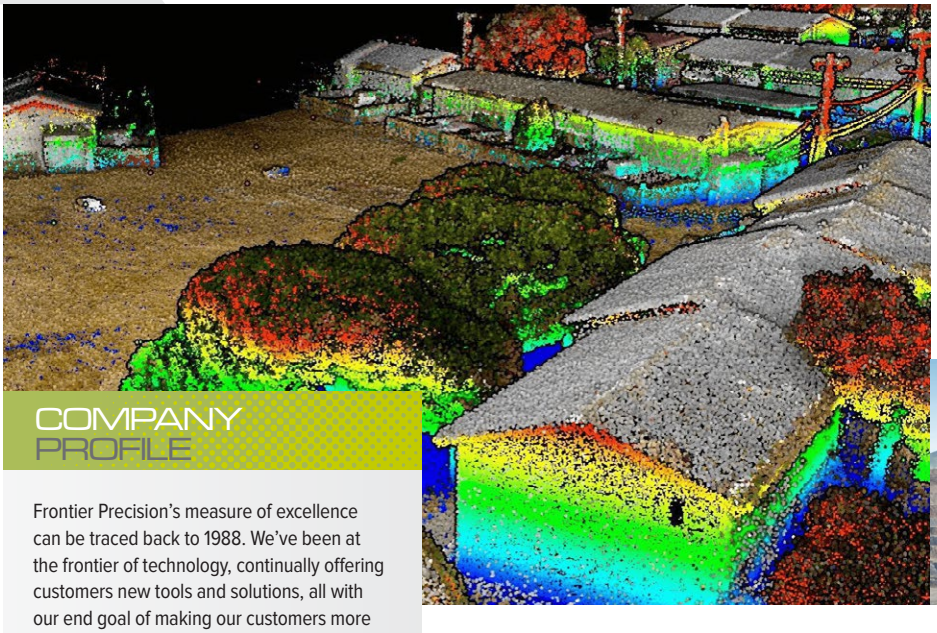
- UNMANNED
- SCANNING
- MONITORING
- CONSTRUCTION
- MOSQUITO & VECTOR CONTROL



COMPANY PROFILE

Frontier Precision's measure of excellence can be traced back to 1988. We've been at the frontier of technology, continually offering customers new tools and solutions, all with our end goal of making our customers more efficient, productive, and profitable with today and tomorrow's technology. Frontier Precision is an employee-owned company—offering solutions in Survey, Mapping & GIS, Drones/UAS/Unmanned, Construction, Scanning/Imaging, Mosquito & Vector Control, Water Resources, Invasive Plant Control. We became one of Trimble's largest geospatial dealers worldwide by offering our customers the solutions they need. Every day, we bring it to life by seamlessly connecting our physical and digital worlds to use technology to improve how we all interact better with the earth—in all kinds of meaningful ways.

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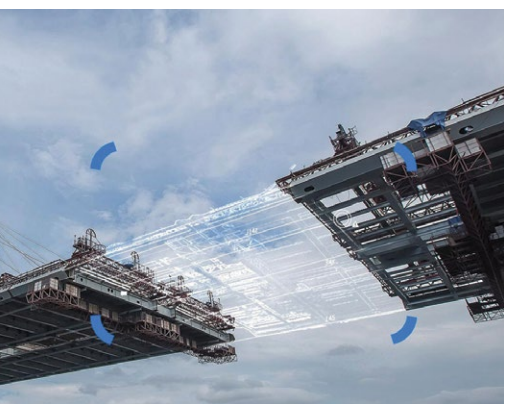

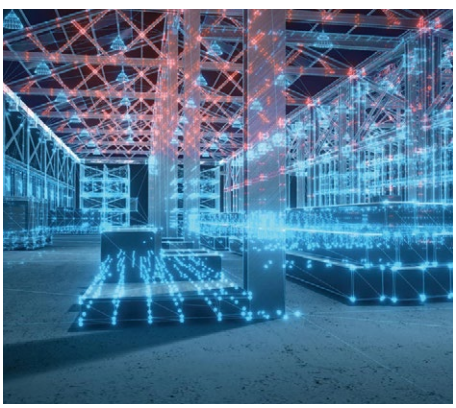

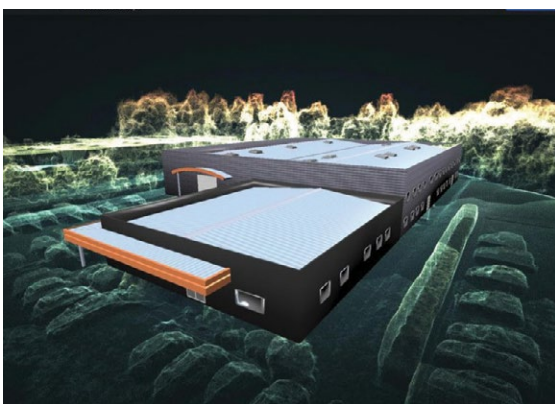

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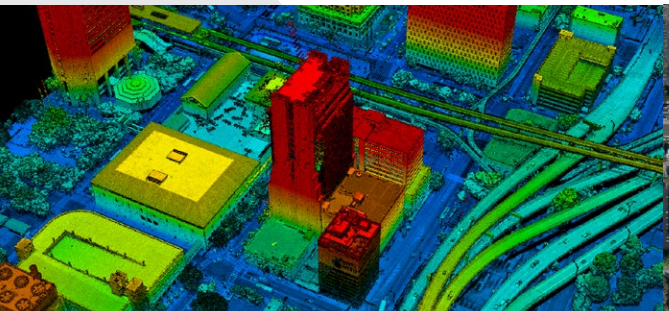

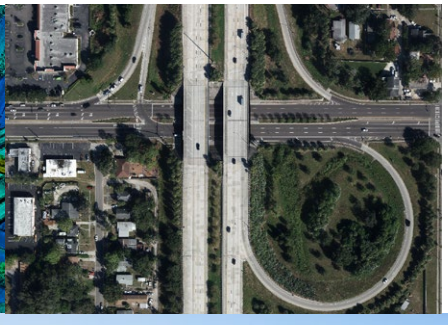

APPLICATIONS

- MAPPING
- SURVEYING
- GIS
- LIDAR
- ORTHOPHOTOGRAPHY
- PHOTOGRAMMETRY
- GEOMATICS

COMPANY PROFILE

GPI Geospatial, Inc. has been a premier geospatial solutions provider for over 48 years. Our mission is to map the foundation for infrastructure improvements that enhance the connectivity between people and communities. We provide innovative surveying and mapping solutions to state, local and federal governments, as well as private-sector clients. Our team understands the value and precision of geospatial data and is committed to providing a customized approach using state-of-the-art sensors, software, and methods to deliver accurate and complete information for design and planning purposes. GPI owns and operates multiple aircraft and vehicles equipped with imagery and Lidar sensors to provide customized solutions for our clients, whether it's from the air, ground, or mobile platforms.

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GPI Geospatial provides our clients with accurate and reliable geospatial data through remote sensing, land surveying, photogrammetry, and GIS services. By combining advanced lidar and imagery acquisition from multiple platforms with precise geomatics practices, GPI's clients are able to benefit from highly detailed topographic, planimetric, and analytical data in CAD and GIS formats. Our wide range of services and skills enables GPI to support multiple markets, including transportation, aviation, private and commercial development, energy, utilities, and the public sector.

GPI specializes in aerial lidar and photogrammetry, mobile lidar, terrestrial static lidar, land surveying, GIS, and CAD services. Our staff is comprised of industry professionals who have extensive technical knowledge and training, many of whom are licensed surveyors, ASPRS Certified Photogrammetrists and Mapping Scientists, GISCI GIS Professionals, Project Management Professionals, and FAA Certified Pilots.

Our fleet of aircraft, mobile mapping vehicles, and survey crews are equipped with lidar and imaging sensors that are capable of capturing millions of data points for our projects. By utilizing advanced Riegl lidar systems, various imaging platforms, and advanced surveying equipment, we can capture rich datasets, which are then used by our photogrammetrists, lidar specialists, and CAD experts to extract topographic, planimetric, and GIS data.

Geospatial and surveying services are the lifeblood of our company, so we take pride in maintaining client relationships and delivering superior work products.

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- Energy Market Experts
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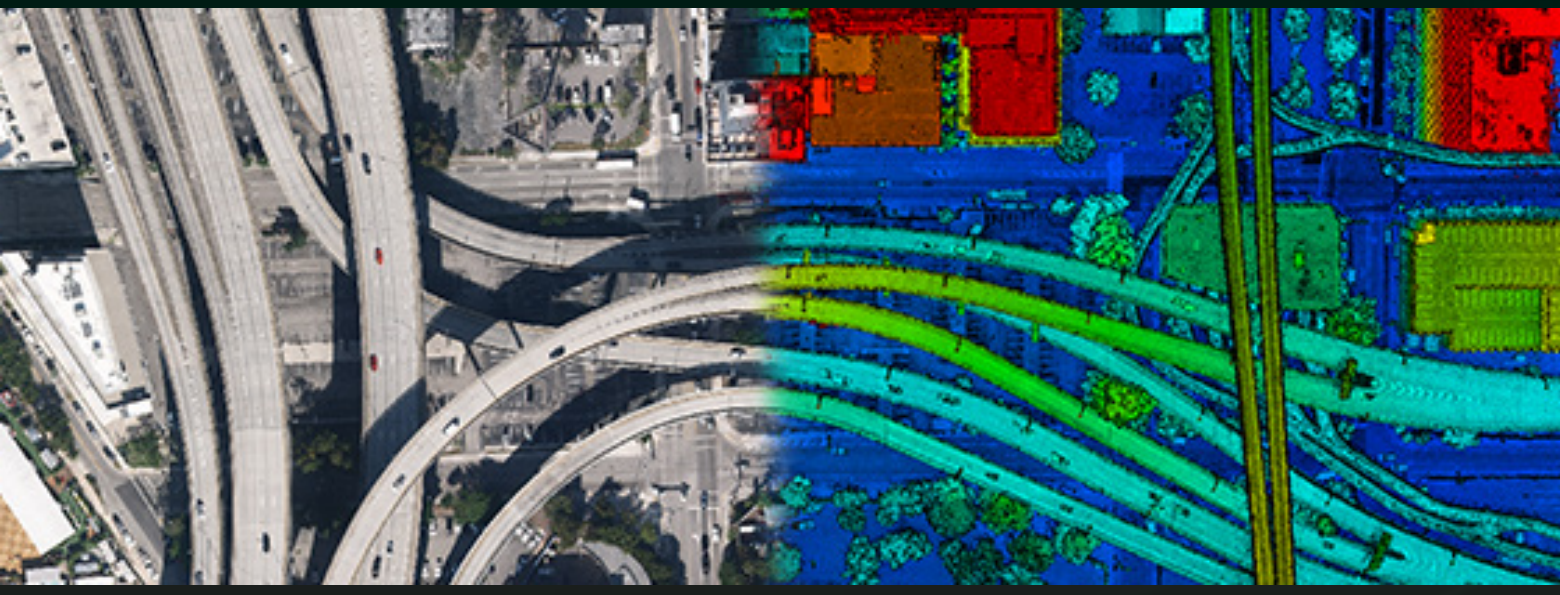

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- LIDAR
- OBLIQUE
- ANALYTICS
- SAAS
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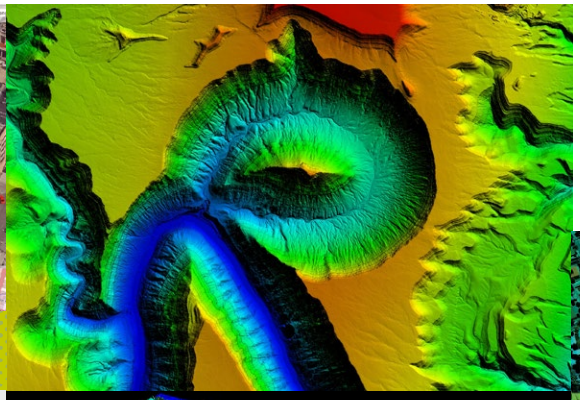

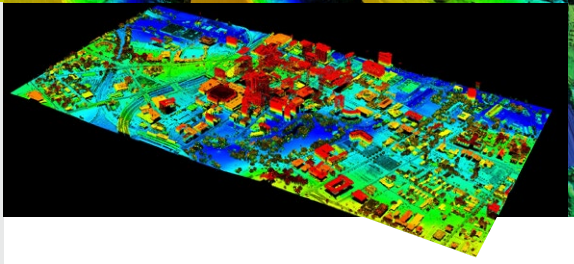

COMPANY PROFILE

Sanborn is an innovator in the modern geospatial industry, delivering state-of-the-art mapping, visualization and 3D solutions for customers worldwide. The firm operates a fleet of aircraft located strategically across the United States. Embracing cutting-edge technology, Sanborn specializes in oblique aerial imagery, aerial and mobile lidar, aerial orthophotography, 3D modeling and visualization software and services, SPIN indoor mapping , unmanned aircraft system (UAS) sales, services and image processing, and a host of geospatial software products.

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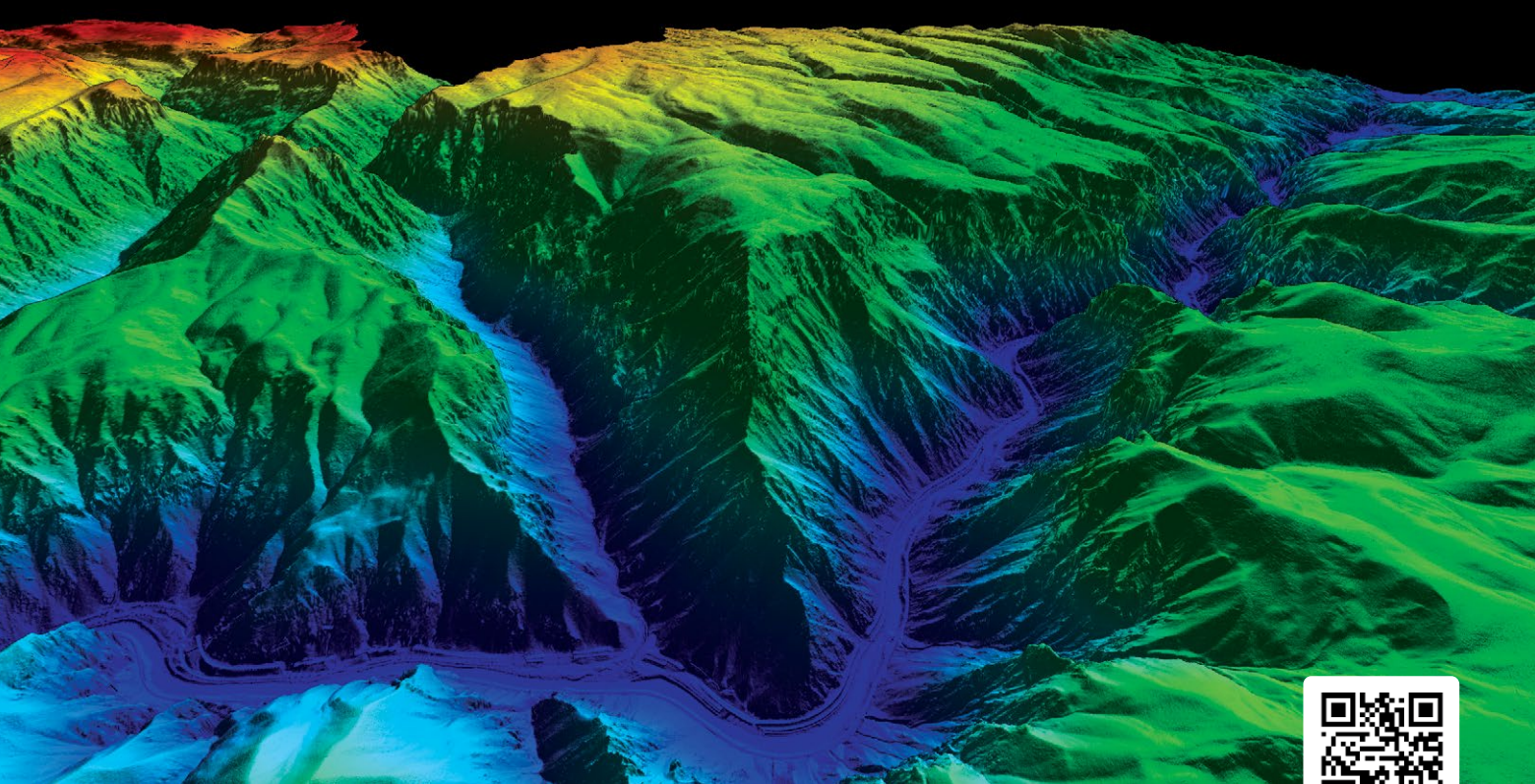

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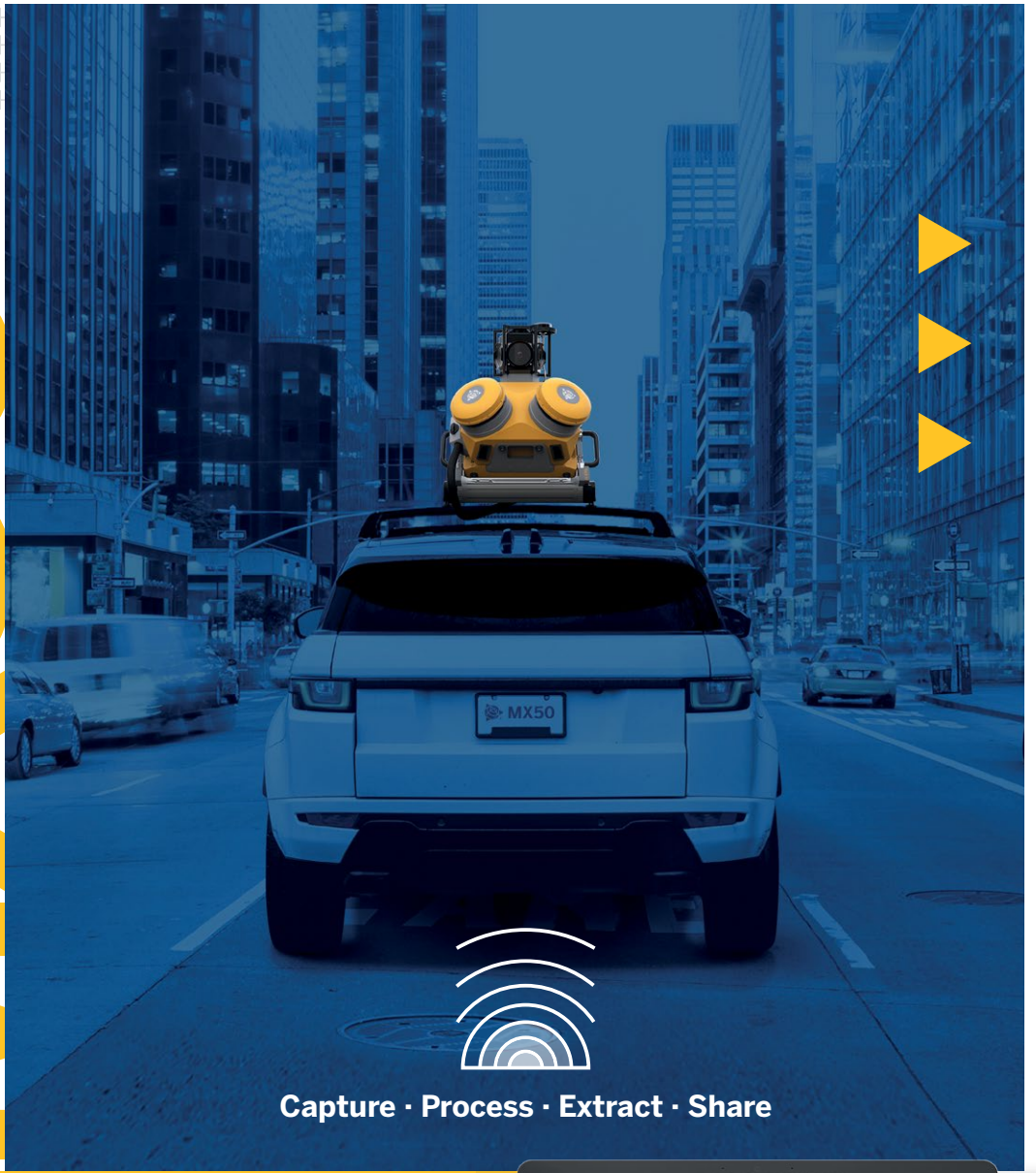

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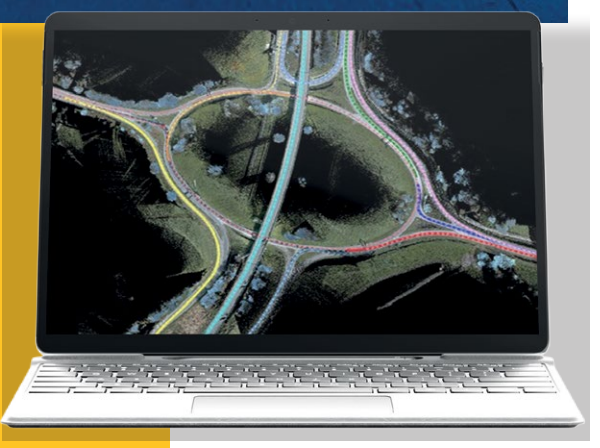

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Microdrones

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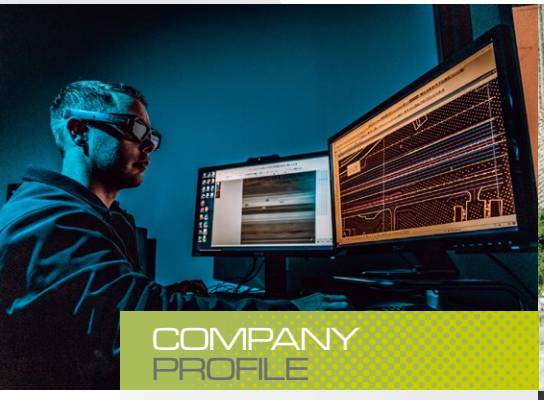
- FORESTRY



COMPANY PROFILE

Microdrones grew out of the collaboration between the German inventor of the world's first commercial quadcopter and a determined surveying payload and software developer in North America. The result is a global aerial mapping technology company that delivers complete and reliable mapping systems specifically developed for the surveying, mining, construction, oil & gas and precision agriculture industries. Microdrones Integrated Systems are industrial tools addressing specific complex mapping challenges for professional customers, relying on a fully integrated geospatial workflow that enables cutting-edge software technology from Microdrones to transform raw data collected in the field by Microdrones survey equipment into valuable high-quality survey grade data. Microdrones is widely recognized for its LiDAR technology leadership.

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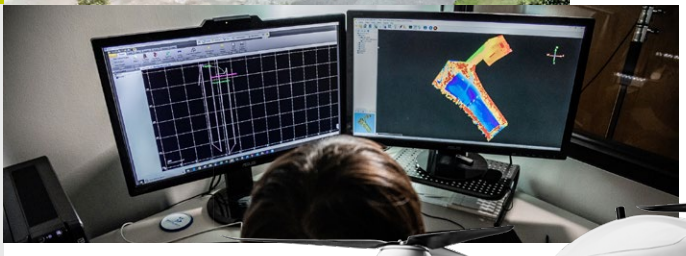

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Relocate, Reappraise, RECON

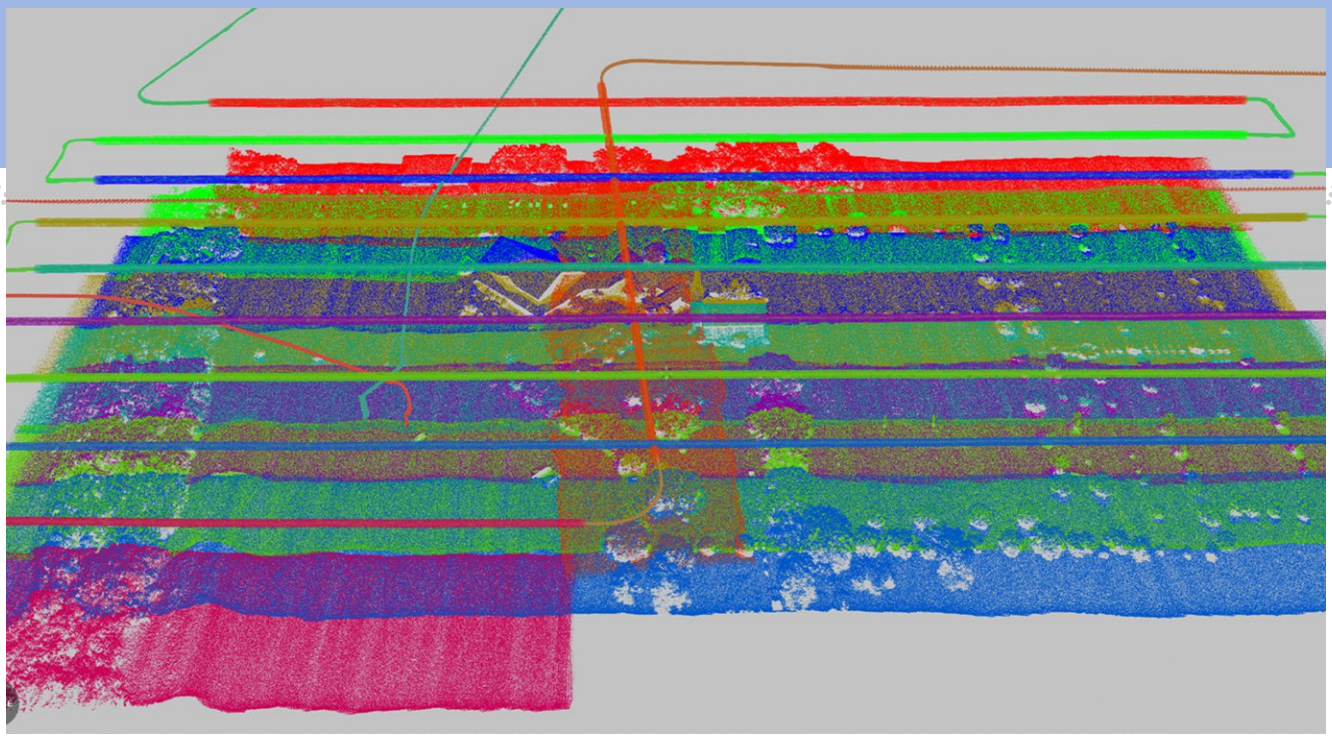
Phoenix LiDAR Systems expands growth potential through cost effective lidar

BY ABBY CHEW

Phoenix team outside its new headquarters in Austin, Texas.

Nine years ago Phoenix LiDAR Systems introduced commercial drone lidar to the market, in what is now a global industry. The company boasts an impressive list of industry firsts over the years. In 2013, it launched the first real-time 3D point-cloud visualizer that helped reduce data acquisition errors in the field. Just two years later it developed the first fixed-wing UAV with lidar integration. The need to increase both range and speed, and to improve the protection of lidar equipment from rough landings, led Phoenix to create the first VTOL fixed-wing UAV-lidar system in 2016. In a remarkable year of innovation, it launched in 2017 the formation of the first real-time 3D point cloud with RGB fusion, the first cloud-based lidar post-processing platform, and the first UAV flight-planner tool. Phoenix has proven itself to be an innovator and an established leader in commercial UAV-lidar systems.

As innovation continued to expand, both in lidar technology and software for streamlined data acquisition,



Screenshot from PC Master, showing flight lines and lidar coverage.

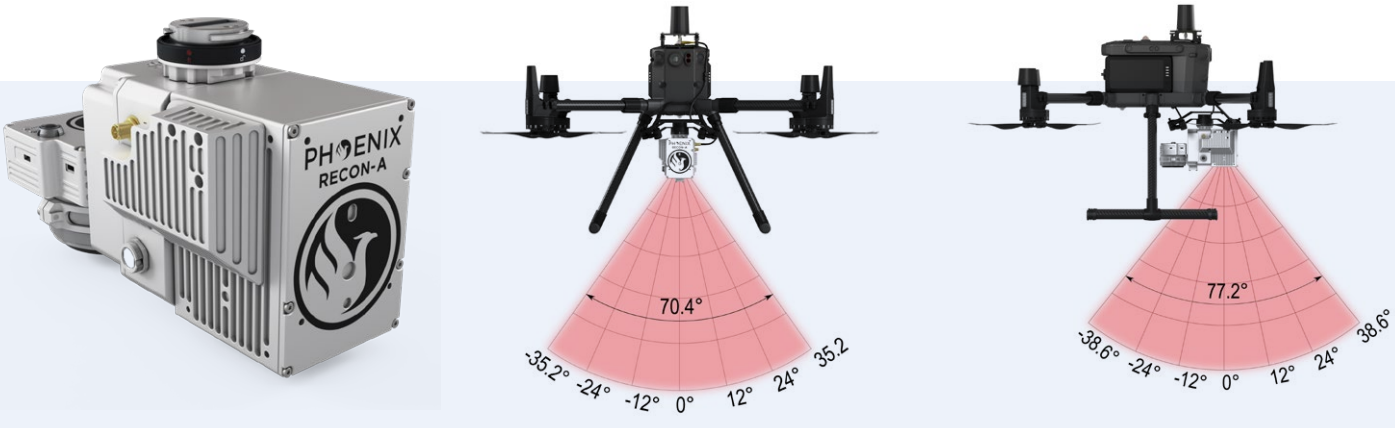
Phoenix realized it had outgrown its facility in Palms neighborhood in Los Angeles. With plans for a larger, more centralized location better suited to its growing success, Phoenix decided to relocate to the rapidly growing metropolitan city of Austin, Texas.

Relocation

Phoenix is delighted to have moved to Austin. The genesis of Phoenix and the experiences fostered in California allowed the company to open up the industry, and create a framework for others to follow. Since those first innovations, the lidar market has exploded, and it was apparent that the next phase would require new ideas, a 'tech-forward community', and the physical space to accommodate growth. The relocation has afforded Phoenix these competitive advantages. Though now officially Texan, the company has retained much of its California 'style' and a belief that forward-thinking solutions combined with a diverse team of top talent is the most important strategy for growth. The team has developed an 'open door' policy at the Austin headquarters, and welcomes customers and friends to visit and see the latest ideas in action.

Lidar market

The lidar drone market is growing significantly, which can be attributed to the increasing number of end-users across many different applications. According to a market analysis by



Views of RECON-A, shown here with Livox Avia, from left to right: system mounted on DJI M300; close-up of lidar sensor as integrated by Phoenix; horizontal and vertical lidar fields of view.

Views of RECON-XT, shown here with Hesai PandarXT, from left to right: system mounted on DJI M300; close-up of lidar sensor as integrated by Phoenix; horizontal and vertical lidar fields of view.

Mordor Intelligence, the UAV-lidar market was valued at $74.96m in 2020 and is projected to reach a value of $525.86m by 2026. The growing requirement for data acquisition and surveillance is also predicted to drive the market forward. With the demand for UAV-lidar becoming increasingly more widespread among different industries, it is surprising that more companies are not choosing to utilize this technology. One reason is premium pricing. Highly advanced remote sensing technology is known to come with a high price tag, which is the primary factor limiting its full growth potential. Phoenix has sought to find a solution to appeal to more price-conscious customers searching for a powerful UAV-lidar solution.

Cost-effective lidar solution

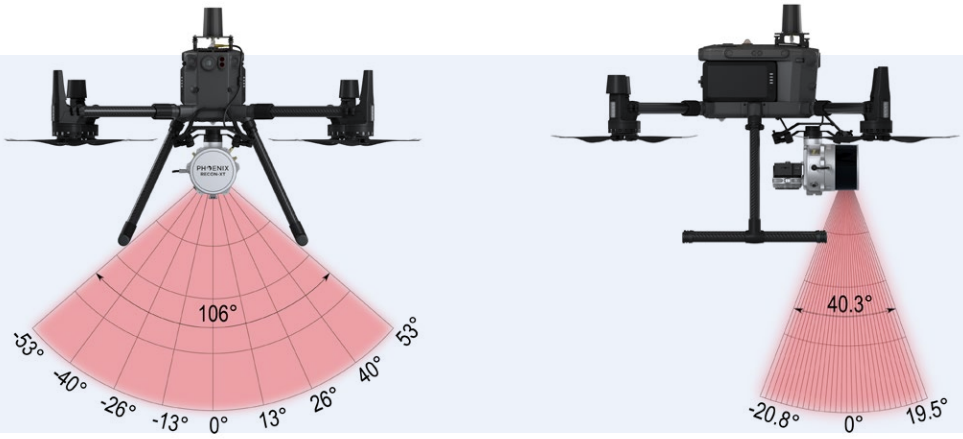
Phoenix, therefore, decided to develop a product series that could broaden the global audience of lidar sensor users. The goal was to build cost-effective lidar solutions that could provide lifetime value and flexibility for customers. Thus the RECON series was born.

> "The RECON series provides a user-friendly experience at a lower price point, enabling more businesses and individuals to become involved in using aerial lidar."

The intention is to expand the global lidar mapping market, through education and lower barriers to entry. The RECON series provides a user-friendly experience at a lower price point, enabling more businesses and individuals to become involved in using aerial lidar. Phoenix hopes that cost-effective hardware paired with intuitive workflows will enable more customers to take the leap into lidar.

Phoenix aims to minimize bloated costs and overhead, passing the savings on to customers to provide them with a no-frills lidar experience. The desire is to democratize lidar for new and inexperienced customers, opening new doors and making the industry larger overall. This is achieved by cutting out nice-to-have features from legacy systems, leaving only raw lidar performance.

Emphasis was placed on trimming the premium features of current solutions, retaining the high performance. The RECON series does not sacrifice high-quality scanning, but simply offers the most lightweight, flexible options at a price point that brings value to the end user. This process involved removing some of the premium features of the SCOUT and RANGER series. Technical changes were made to minimize weight and profile of the RECON series so that it would fly efficiently on the DJI M300. Cost of operations and costs per acre scanned were reduced by optimizing the acquisition process and simplifying the workflow to the point where in-person

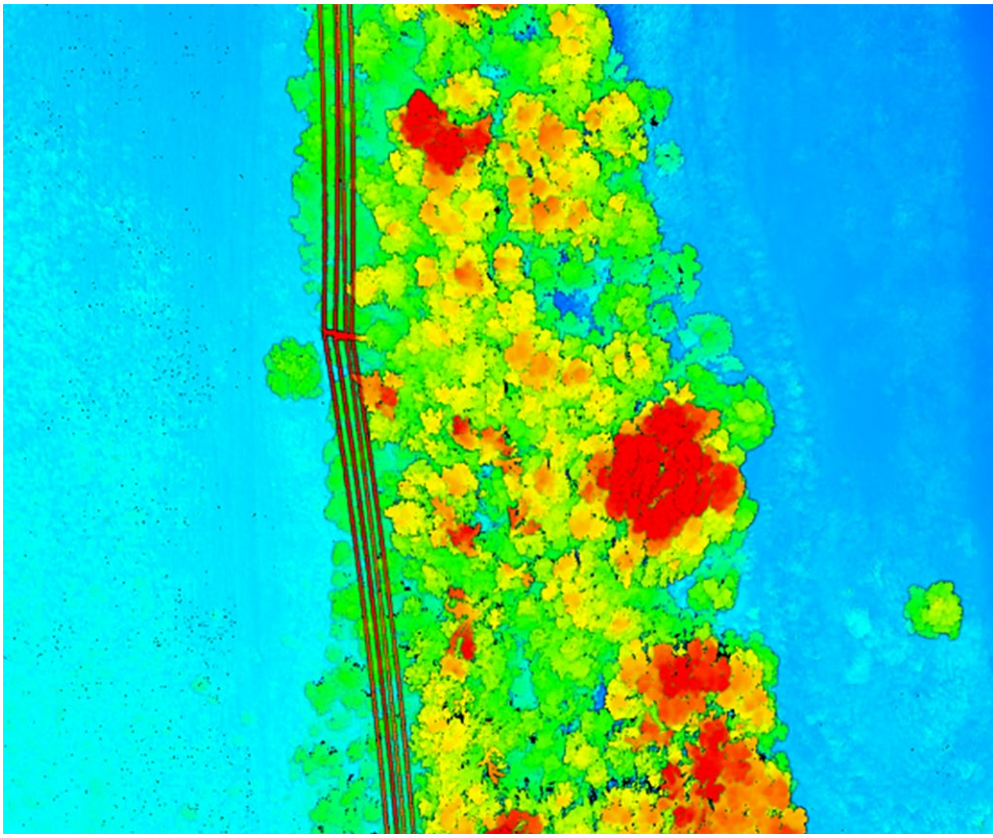


training is not needed. The simplicity of acquiring and processing data from the RECON series has revolutionized the Phoenix workflow and passed the benefits to customers. The goal is to help customers save, not just on up-front costs, but on training and operations costs over its lifetime.

The Livox Avia and Hesai PandarXT sensors were extensively tested and proved to be valuable and cost-effective. Phoenix found them to stand out in their class from a performance and value perspective. The company chose to move forward, integrating these sensors into the RECON series.

Changes to the PLS workflow

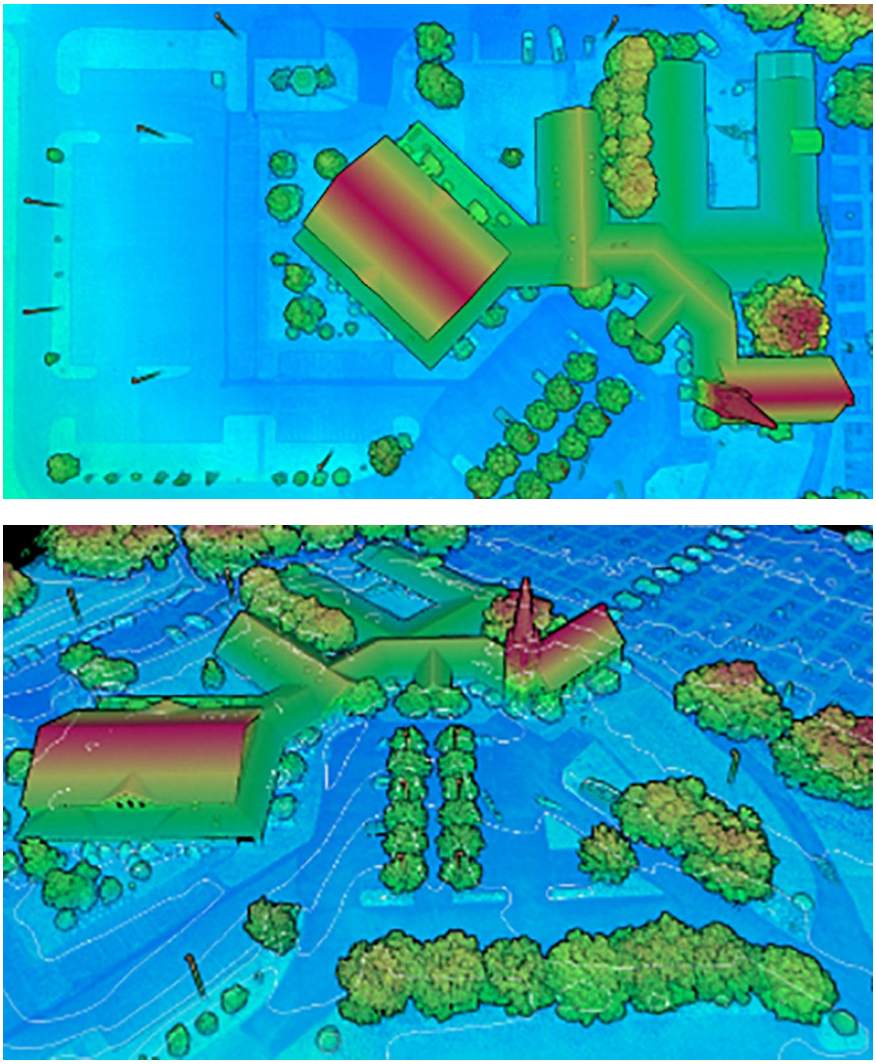
Phoenix has introduced a complementary software package that is extremely lightweight and efficient. PCMaster Suite allows the end-user to fuse and colorize point-cloud data, provides a straightforward workflow for LAS export and easily integrates with their own workflow for specific use-cases. PCMaster Suite embodies a truly simplified, one-click workflow and removes the training headaches. Users can process trajectory and lidar data together with minimal steps, producing a LAS file with ease.



Detailed capture of distribution utility lines over a corridor of dense vegetation. Captured by RECON-A.

Flexibility options

The RECON series comprises two models. RECON-XT can be mounted to any vehicle, land, sea or UAV, resulting in a lightweight lidar solution that can accomplish any job. The RECON-A is designed for mounting on a DJI Enterprise Series UAV. The RECON



Dense UAV-lidar mapping dataset, symbolized by height and intensity, with smoothed contours overlaid. Captured by RECON-XT.

units can be powered from the auxiliary power port, making them agnostic to the vehicle used to capture data. Using the GUI, users can stop and start recording wirelessly from their mobile device. This facilitates control of the unit from anywhere, even if it is not accessible during data acquisition. RECON units record on to external USB storage and can accept a number of USB 3.0 devices. Thus there are no storage limitations during data capture, as adding more storage is as simple as plugging in another empty USB drive.

For UAV flying, the RECON Series was designed for DJI enterprise drones such as the M300 and M200 series. The RECON series is natively compatible with the DJI Skyport interface on the Matrice aircraft: power will be provided to the payload through the Skyport, making setting up and tearing down faster and reducing time spent in the field. Thus the RECON series is ready to fly on any DJI enterprise drone, with a maximum flight time on the M300 of 35 minutes. Thanks to its auxiliary power port, any vehicle can carry the RECON series and Phoenix has ensured that integration will be possible with a number of vehicles. The mission-planning portion of the workflow is done inside Phoenix Flight Planner, which is web-based service software to calculate flight plan, review estimated lidar data quality, and upload a terrain-following KMZ directly to the UAV before flight. The tool allows missions to be exported to a number of flight applications and aircraft.

Use cases

The RECON models are both quality, budget-focused systems, but they do have individual characteristics. The RECON-A is excellent for UAV -scanning of power lines as its optional laser pattern facilitates high-density scans on low-reflectance transmission lines. The RECON-A offers two scanning pattern options. The user can select repetitive-line scanning where the laser simply moves back and forth horizontally to capture the highest precision data, while reducing noise and point cloud file size. Users also have the ability to utilize the optional non-repetitive scanning mode, in which the laser forms a star-like pattern and optimizes the sensor's abilities

to pick up very small, low-reflectance targets such as dark power transmission lines. It also excels in the surveying of towers. The RECON-A is the most cost-effective system Phoenix has offered.

The RECON-XT includes an auxiliary mount, combined with its 360° laser, so it can be adapted for use in mobile or backpack scanning. Thanks to versatility and low cost, capturing data from a mobile or backpack scanning mission is possible at a fraction of the cost of more traditional lidar systems. The RECON-XT is the most value-oriented system Phoenix offers, with a very low barrier to entry, so it fits survey firms, and businesses alike. The system's well-rounded abilities suit it to many different applications, including penetration of vegetation, open-pit mining, glacier surveying and monitoring.

Unlimited support

Phoenix offers its new CARE service program, an annual service offering unlimited support on the RECON series. In addition, customers are granted full access to training video series, supporting documentation and the Phoenix Flight Planner tool. Phoenix is dedicated to ensuring the success of customers. The CARE program is designed to support the RECON systems and customers. Each RECON system comes with one year of CARE, with options for annual subscription renewal, up to a total of three years.

Future of RECON

Phoenix plans to add several accessories and features to the RECON portfolio. Development of georeferenced photogrammetry is under way, as well as backpack and roof-rack accessories for the RECON series. The company is exploring further optimization of the workflow and how to increase the lifetime value for customers.

The excitement about the cost-effective RECON series is evident and Phoenix has taken steps to ensure customers can bring RECON units fully into its software environment. Full compatibility with LiDARMill, a cloud-based processing suite designed to make processing and managing point-cloud data very simple, is under development. PCMaster is a fine tool for customers seeking a simple workflow, but LiDARMill is an all-inclusive service that will processes data in an automated manner and allows users to store their point clouds online, protected by the cloud. This is key to disseminating information to members of customers' teams. LiDARMill Viewer gives anyone access to the point cloud in a browser window. The barrier to entry for lidar data analysis has been reinvented by LiDARMill and the intent is to bring this complete solution to market.

> "The barrier to entry for lidar data analysis has been reinvented by LiDARMill and the intent is to bring this complete solution to market."

The RECON series was developed as a direct result of changing market conditions, including promising new sensors and upgrades to Phoenix's navbox and camera. The RECON series will retain its goal of cost-effectiveness, and ease of use, but the company will strive to deliver the best solutions to customers during these rapidly changing times in the world of technology.

Conclusion

The lidar world is evolving so rapidly that the last two or three years have seen more innovation than the preceding decade. Previously second-rate "automotive" class sensors have become so advanced that they are being increasingly used for mapping purposes. Lidar data has become more democratized with the expansion of cloud-based services for processing and hosting point cloud data.

Phoenix hopes that lidar will become increasingly more affordable and easier to use. These benefits should expand the market as a whole and increase the number of use cases for lidar systems, enabling even more of our world to be captured using lidar.

Abigail Chew is the global marketing coordinator at Phoenix LiDAR Systems. She graduated in 2020 with degrees in both marketing and sales from the Perdue School of Business. Highly motivated and career-driven, Abigail has experience working in b2b sales and marketing, event planning, brand promotion, media analytics, and managing contemporary digital tools, platforms, and channels. When she is not producing various types of content to expand Phoenix's digital footprint, Abigail works with the sales team to implement new strategies and tactics to continue growing the company's global presence within the commercial lidar drone industry.

EVON SILVIA

LAS Working Group Releases Standard ExtraByte Registry

2021 was not the post-pandemic year we all hoped it would be. As covid fatigue settled in, committee participation and other non-essential work diminished to a trickle for lack of energy. I'm no exception—my own contributions to this magazine have been far less numerous than intended and my naïve predictions for LAS 1.4 R16 publication in 2021 fell short as activity stalled for most of the year. With conferences canceled or struggling to survive as virtual events, volunteer participation in organizations like ASPRS has been down all year long while we all continue to white-knuckle our way through a global pandemic.

Nevertheless, despite kids screaming in the background, cats lounging on keyboards, sourdough needing constant attention and omicron rearing its ugly head, the ASPRS LAS Working Group (LWG) has convened three times since our last written update in mid-May[1]. Here's a look at some of the topics covered in the May, July and November 2021 meetings and currently in work.

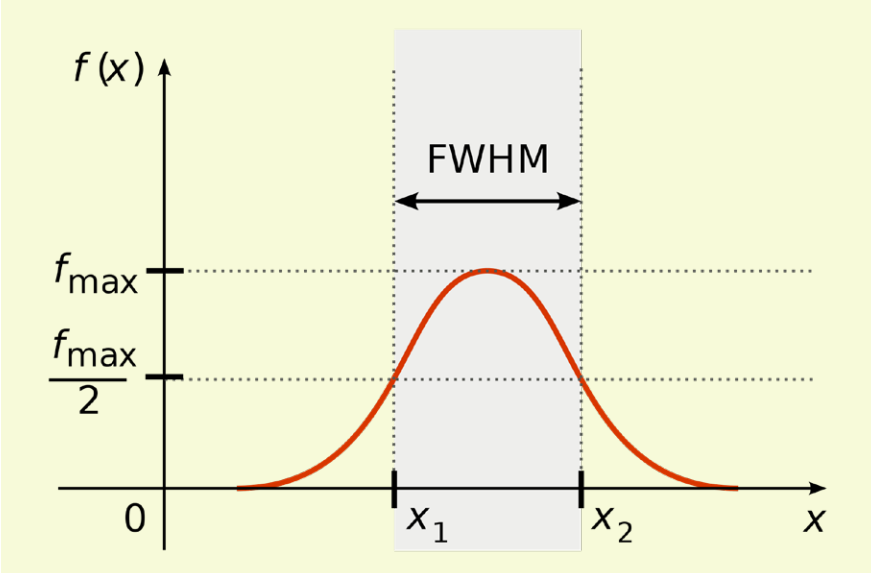


Figure 1: Full width at half maximum (FWHM) bandwidth, as used in the Echo Width ExtraBytes definition.

Creative Commons image from Wikipedia: https://en.wikipedia.org/wiki/Full_width_at_half_maximum#/media/File:FWHM.svg.

Topobathymetric Lidar Domain Profile v2

The topobathymetric lidar community has evolved considerably since the first release of the topobathymetric lidar domain profile (LDP) in 2013[2]. The community has rallied around the LDP, with some adaptations that can and should be standardized in an update[3]. Items being addressed include:

- Adjustment of topobathymetric classifications, such as clarification for water surface (41) and submerged noise (45) classes, removal of IHO object class (44) and addition of a submerged vegetation class (46)
- Overhaul of topobathymetric ExtraBytes
- Migration to the LAS wiki
- Release of Version 2 of the topobathymetric LDP

Since the topobathymetric LDP is the only LDP currently in publication, its iteration sets the precedent for handling LDPs under the GitHub management paradigm. In November 2021, the LWG agreed that the wiki would be an appropriate place to store the LDPs, if a versioned static PDF copy of each LDP could be made available for referencing in tender documents.

1 https://lidarmag.com/2021/05/22/las-exchange-las-working-group-releases-first-public-registry-2/

2 https://www.asprs.org/wp-content/uploads/2010/12/LAS_Domain_Profile_Description_Topo-Bathy_Lidar.pdf

3 https://github.com/ASPRSorg/LAS/issues/117

Several other domains could potentially benefit from standardization around LDPs, such as transportation, electrical utilities, or oil and gas, and we invite contributions from experts in each domain.

First Standard ExtraBytes published

Following its success publishing the Standard System Identifier registry, the LWG is in the process of publishing its first standard ExtraBytes definitions[4]. The wiki states:

> *"A point has "extra bytes" when the Point Data Record Length in the LAS header is set to a larger value than the minimum required by the Point Data Record Format. LAS 1.4 introduced a new VLR[5] that describes these "extra bytes" with one descriptor per attribute.*
>
> *"Adding Standard ExtraBytes to this registry makes it easier to create and understand these optional point attributes across different software packages and applications."[4]*

During an extended meeting in summer 2021, the LWG established the following guidelines for standardizing an ExtraByte:

- The meaning and formal name of the ExtraByte field must be consistent across all usages, and lowercase names are preferred
- An identifier field will be added to the ExtraBytes VLR in a future revision
- The units and data type for an ExtraByte will be considered standard—deviations are allowed but will be considered non-standard
- Description, scale, offset and NODATA values will be recommended but not required

As of this writing, three ExtraByte definitions have been identified as having passed review:

- Beam ID—an extension of the existing Channel field in point formats 6-10 to support more than 4 possible values
- Echo Width—an approximation of the curve width of the returning echo's waveform that is calculated during the full-waveform digitization (**Figure 1**)
- Height Above Ground—height of the point compared to a reference surface such as the ground, canopy or water

Other definitions will follow, especially as LDPs continue to develop. Readers are invited to propose their own Standard ExtraByte definitions by filing a new Issue on the LWG GitHub page[6].

Wiki updates

In addition to the release of the Standard ExtraBytes registry, the LAS wiki[7] received several other updates in 2021.

In fall 2021 the LWG began a registry of user-contributed VLR definitions[8] to the LAS wiki. This fresh, exciting page provides a location for open-source projects, governments and even private companies to voluntarily contribute VLR definitions that are associated with their publicly registered VLR keys[9].

Although VLR publication is entirely optional, doing so in a central location enables users to derive even greater value from community-created VLRs and the LAS files in which they live. BayesMap Solutions began the process with the first contribution, then others committed to follow. If readers would like to make a contribution, I would be happy to assist if interacting with GitHub's wiki format is not comfortable.

Other additions to the wiki include:

- Clarification of the complex LittleEndian and BigEndian nature of the LAS header's ProjectID and addition of example files (Issue #111[10])
- Addition of the "How to View Edits" page[11] to assist maintainers wanting to review their edits in the resultant PDF
- Explanation of storage size encoding for full-waveform data[12]

Preparing for LAS 1.5

Work has begun on LAS 1.5, the next version of the LAS specification[13]. Although the LWG is reluctant to iterate LAS after the sluggish and disruptive adoption of LAS 1.4, two important and pressing problems can only be mitigated by the release of a new version.

Address loss of GPS time precision

Adjusted Standard GPS Time as defined in LAS 1.2 through LAS 1.4 has been losing precision since 2011. In fact, it has been unable to designate

4 https://github.com/ASPRSorg/LAS/wiki/Standard-ExtraByte-Definitions
5 Variable Length Record
6 https://github.com/ASPRSorg/LAS/issues
7 https://github.com/ASPRSorg/LAS/wiki
8 https://github.com/ASPRSorg/LAS/wiki/User-Contributed-VLRs
9 https://www.asprs.org/misc/las-key-list.html
10 https://github.com/ASPRSorg/LAS/issues/111
11 https://github.com/ASPRSorg/LAS/wiki/How-to-View-Edits
12 https://github.com/ASPRSorg/LAS/wiki/Waveform-Data-Packet-Descriptors-Explained#storage-size
13 https://github.com/ASPRSorg/LAS/milestone/6

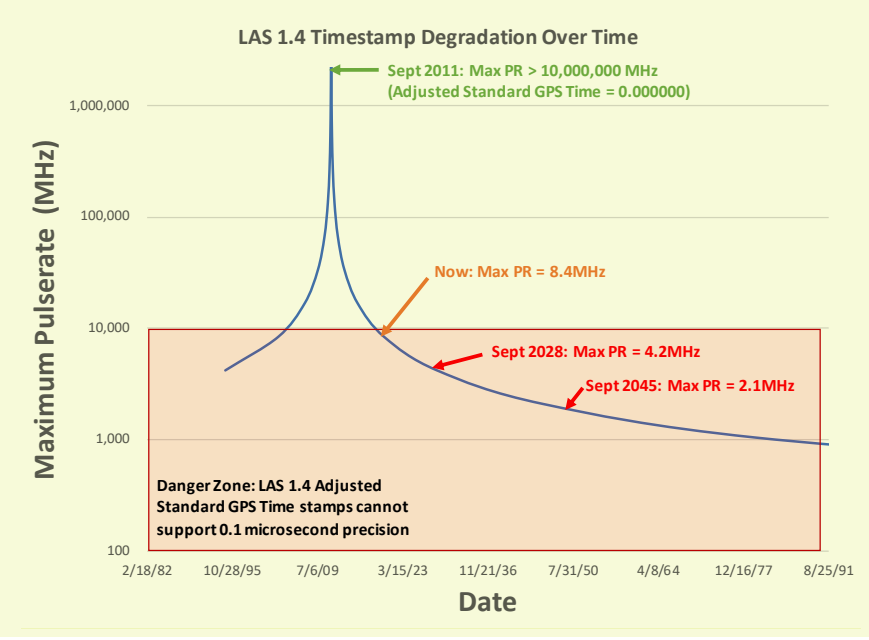


Figure 2: Loss of precision of Adjusted Standard GPS Time and its impact on the maximum possible pulse-rate (PR) that can be encoded uniquely.

timestamps with 0.1-microsecond precision (~8 MHz) since 2015, and it will be unable to differentiate past 0.2-microsecond precision (~4 MHz) in 2028 (**Figure 2**). Given that 2-MHz sensors are already on the market, it won't be long before it is technically impossible to differentiate between pulses using Adjusted Standard GPS Time.

The proposed Offset Standard GPS Time in LAS 1.5[14] will provide the needed flexibility to provide 0.1-microsecond precision or better for any 8-year period, with minimal coding needed to add support. A table of recommended standard offset values will be provided by the LWG on the LAS wiki to promote standardization.

Adjusted Standard GPS Time will continue to exist in LAS 1.5 using the existing global encoding bit, but this new option will likely require the addition of a new global encoding bit to protect backwards compatibility. Fortunately, the real strength of this proposal is that it will not require the addition of yet another set of point record formats, because it utilizes the existing double-precision float in all modern point formats.

Temporal datum encoding

NOAA NGS is currently working on new datums that are inherently temporal, tied to specific moments in time[15]. Coordinate systems in LAS 1.4 are defined using WKT v1, which unfortunately has no mechanism for defining temporal datums[16]. OGC developed WKT v2 in part to mitigate this issue, and a new version of LAS will be needed, as LAS 1.4 is explicitly tied to WKT v1.

The release of NATRF2022 and related reference frames is expected to be in 2024 or 2025. This gives time to prepare and release LAS 1.5, so long as the software companies keep up with our developments.

Other proposed changes in LAS 1.5

Given that a new version is therefore necessary, we also have the opportunity to introduce new trimmed-down point formats more suitable for point clouds derived from sources other than lidar[17], and potentially encode LDP references in the LAS header itself, rather than relying on VLRs for this information.

Importantly, the LWG rejected a proposal to deprecate the old point formats 0-5 in LAS 1.5[18]. We felt that leaving them helped preserve backwards compatibility. This demonstrates the value of community involvement and soliciting feedback in a public forum that can be reviewed later if the matter resurfaces.

Other modifications will certainly be included as LAS 1.5 is developed. Having learned from the confusion and resultant delays surrounding the release of LAS 1.4, however, LWG intends to make the upgrade from LAS 1.4 to LAS 1.5 as propitious as possible. I expect a release toward the end of 2022 or early 2023.

LWG business and future meetings

Welcome new LWG member Jochen Keil from rapidlasso GmbH[19], stepping in for our dearly missed friend and longstanding LWG veteran Martin Isenburg. Jochen will be a valuable addition to our team.

The agenda for the meeting scheduled for January 17, 2022 was headed by a final review of LAS 1.4 Revision 16 before submission for publication. It also included a review of the wiki updates described in this article. The meeting will be reported in the next article in this series.

Evon Silvia, PLS, is a solutions architect with NV5 Geospatial, Corvallis, Oregon. With his diverse background in civil engineering, land surveying, sensor research, and computer programming, Evon looks at remote sensing a little differently. He has an MS in geomatics and civil engineering from Oregon State University with a focus on lidar and joined Quantum Spatial in 2011 to advance its land surveying and lidar processing divisions. As chair of the ASPRS LAS Working Group, Evon is passionate about data quality and strives to improve collaboration and communication in the remote sensing community.

14 https://github.com/ASPRSorg/LAS/issues/6

15 https://www.ngs.noaa.gov/datums/newdatums/index.shtml

16 https://github.com/ASPRSorg/LAS/issues/95

17 https://github.com/ASPRSorg/LAS/issues/93

18 https://github.com/ASPRSorg/LAS/issues/94

19 https://rapidlasso.de/

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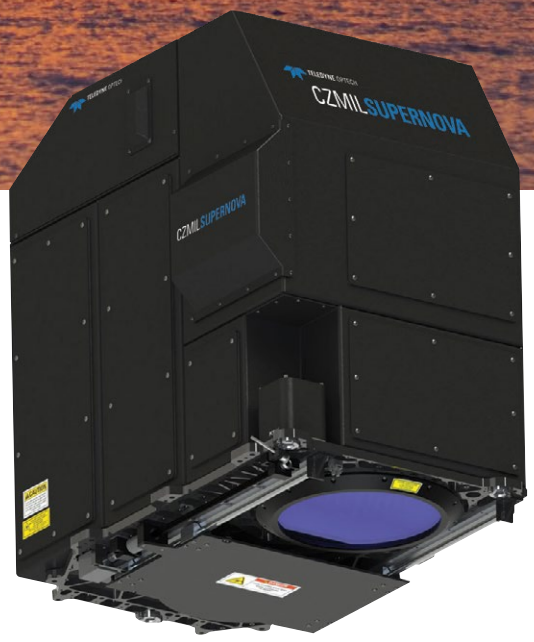

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BY DR. MICHAEL ZANETTI

How Can We Use Lidar on the Moon?

Readers of this magazine already understand the utility of lidar for producing digital terrain models and for autonomous navigation. The same things that make lidar ideal for autonomy and surveying, such as physical range measurements, object detection and hazard avoidance, and 3D mapping, could also be useful for navigation and mapping on the Moon. But, the advancements that have supercharged the uses of lidar on Earth may ultimately be insurmountable hurdles. For off-Earth utility, how can we effectively bridge between the differing technical and engineering requirements for autonomous navigation with those for ultra-high resolution terrain mapping? At odds are the "see-and-scrap" autonomous solution (see the objects, then scrap the data) versus "scan-and-save" (save all the points to make maps).

A lidar-based vision and navigation system for a planetary rover is almost a no-brainer. The illumination conditions at the lunar South Pole – where the Sun is never higher than ~3° above the horizon – are nothing but long-shadows and direct-sun. Stereo-photogrammetry will struggle or require on-board lighting, negating most camera-based vision sensing size-weight-and-power advantages. Lidar's active source imaging capability is likely needed.

The same lidar system which provides hazard avoidance for the rover can also provide ultra-high resolution point clouds of the terrain. The value of ultra-high-resolution terrain mapping of lunar landing and exploration sites is incalculable. Nearly every mission operation to be done on the surface requires topographic context, from where to explore next to documentation of sample locations. Adding construction and habitation facilities to a lunar outpost requires the accuracy and repeat mapping capability of lidar. Arguably most important element is the curation and public engagement opportunities that lidar context mapping provides. Being able to know, in >50 years' time, exactly what was done on the surface, and being able to virtually take the public to these areas, will be magnificent.

To test operational methods (how to effectively scan and map) we can use Earth-based ground-lidar systems, like TLS and Mobile mapping solutions. These are helping us to understand and optimize path planning and field of view, and the advantages and disadvantages of mobile mapping versus TLS. But, the real challenges that may prevent lidar from being used to its full potential are engineering based, not with the sensors themselves (thermal, vacuum, and radiation issues can be solved), but with the data volumes produced and the transfer of these enormous volumes of data. Space-hardened computers currently can't provide the on-board computing needed for sophisticated 3D lidar simultaneous localization and mapping (SLAM). While optical communications to the Moon may soon be possible, even that expanded bandwidth may not be sufficient for beaming back gigabytes of data. Lidar can certainly be used for navigation (see-and-scrap), but can we actually navigate with lidar *and* save all the data?

Frankly the path forward for the adoption of lidar on the Moon consists of clever solutions to work within the existing constraints of avionics packages for planetary rovers. Developing space-bound computing hardware capable of dealing with lidar data processing, volumes, and transfer is likely too costly. Creative solutions from the lidar industry are needed to help bring this technology to the Moon. Moreover, addressing the challenges of see-and-scrap and scan-and-save are not just applicable for the Moon. Improvements in data compression and handling, rapid reduction of duplicate points, and acceleration of real-time SLAM-to-DEM are all beneficial for the future capture of user data and mapping of Earth environments.

Dr. Michael Zanetti, NASA Marshall Space Flight Center, National Space Science & Technology Center, Huntsville, AL

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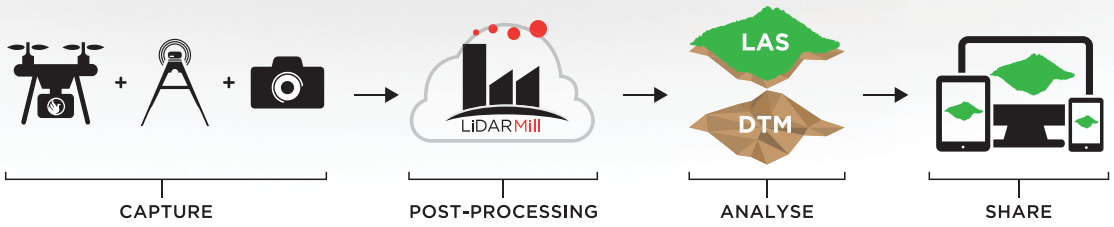

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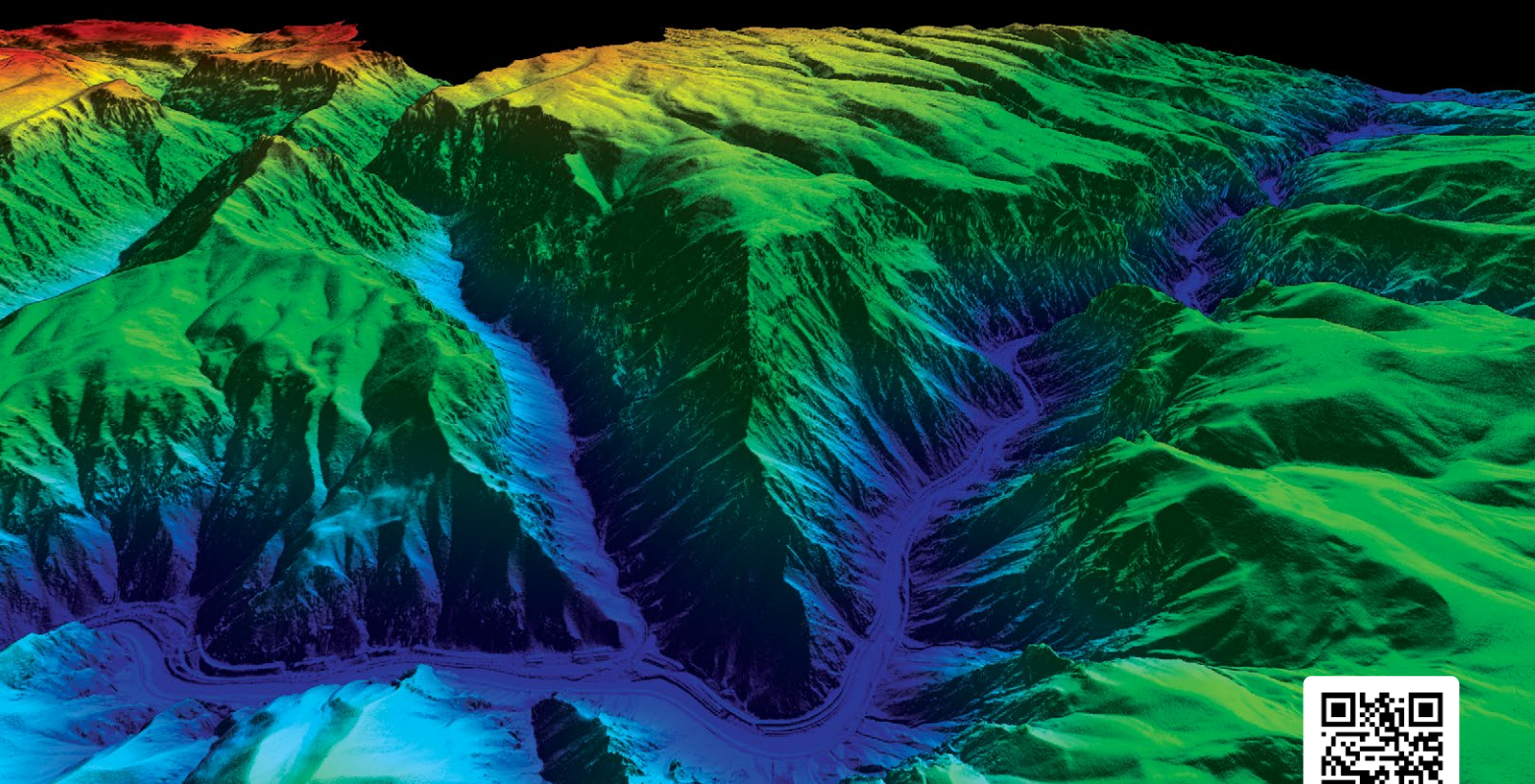

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