VOLUME 8 ISSUE 6

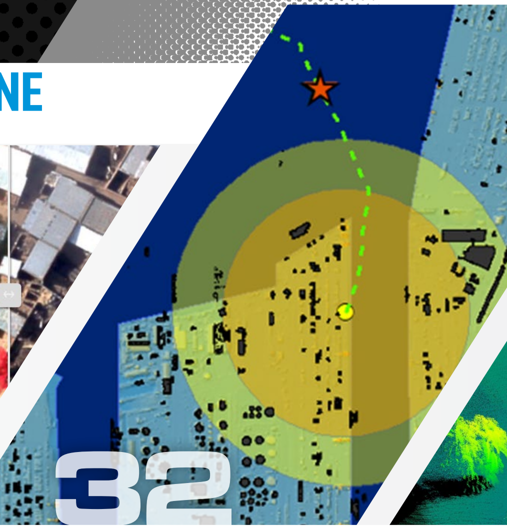
LIDAR MAGAZINE

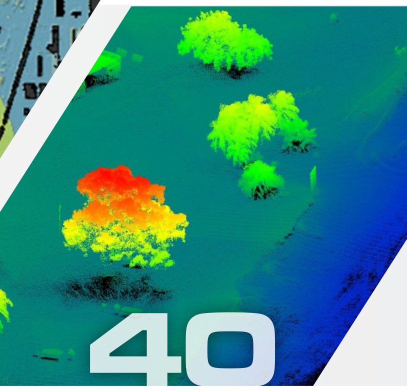
NOV/DEC 2018

FLYING HIGH

IceSat2 Launch

LIDAR MAGAZINE





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The Ice, Cloud and land Elevation Satellite-2, or ICESat-2, is a laser altimeter that will measure the heights of Earth's surfaces. With ICESat-2's high-resolution data, scientists will track changes to Earth's ice-covered poles, which is witnessing dramatic temperature increases. The mission will also take stock of forests, map ocean surfaces, characterize clouds and more.

Image courtesy of NASA's Goddard Space Flight Center.

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DR. A. STEWART WALKER

Lidar flies high

Writing this on board a Lufthansa flight to Germany to participate in the mid-term symposium of ISPRS Technical Commission I, entitled “Innovative Sensing—from Sensors to Methods and Applications”, in Karlsruhe, then the enormous Intergeo trade show in Frankfurt, I look forward eagerly to learning about the latest scientific and commercial developments. The Karlsruhe event enables scientists working on topics on the ISPRS agenda to report on their findings midway between the quadrennial congresses. In Frankfurt, representatives of hundreds of companies will be enthusiastically proselytizing the latest products and services. The struggle will be to see everything important in only three days. It will be marvelous!

These delights scarcely allow breathing space from my last two excursions. On September 15, 2018, thanks to the magnanimousness of Sigma Space (part of Hexagon) and NASA, I was present at Vandenberg Air Force Base in California to witness the launch of ICESat-2 (Ice, Cloud and land Elevation Satellite). This was a once-in-a-lifetime experience and a great honor. Thanks again to Sigma Space, I am able to report in this issue on aspects of the single-photon technology on which this mission is based, especially the detector array, which provides incredibly precise timing for the sole instrument on ICESat-2, the Advanced Topographic Laser Altimeter System (ATLAS). The ATLAS laser emits visible, green laser pulses at

Michael Freilich, director of NASA’s Earth Science Division, NASA Headquarters, signs a star on the United Launch Alliance Delta II with ICESat-2 onboard, on Thursday, September 13, 2018, at Vandenberg Air Force Base in California. This was the final launch of a Delta II rocket. The “381” on the rocket signifies that it was the 381st flight in the Delta family. The first Delta I was launched in May 1960. *Courtesy of NASA.*

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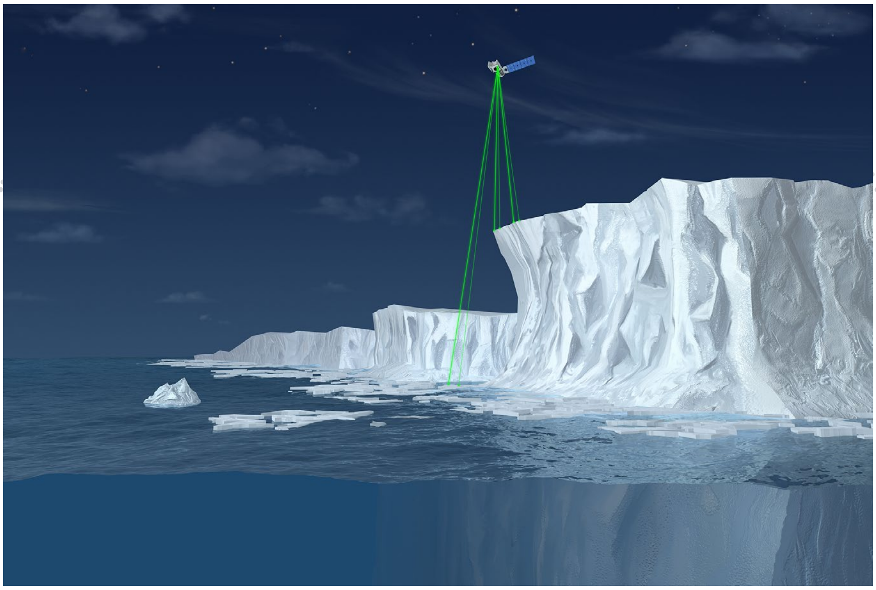
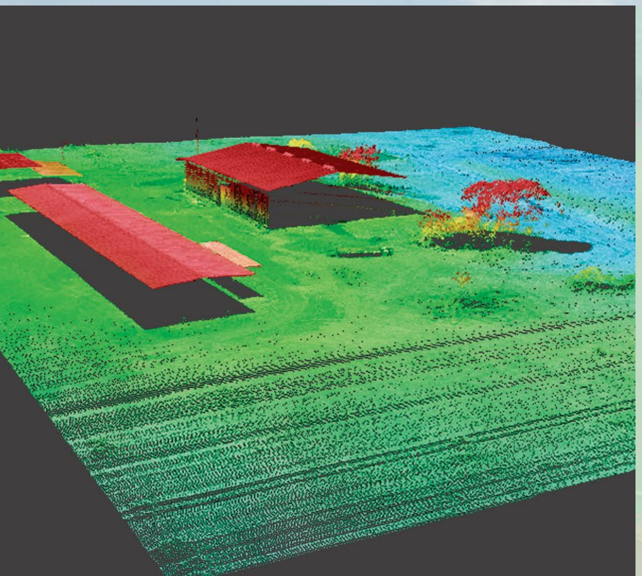


ICESat-2 uses six laser beams to measure the height of ice, as illustrated in this not-to-scale artist's rendering. This illustration is an outcome of the ICESat-2/SCAD Collaborative Student Project.
Courtesy of NASA

a wavelength of 532 nm. ATLAS splits the laser into six beams, arranged in three pairs, with 3.3 km between pairs; it fires at a rate of 10 kHz, enabling points on the ground to be captured at 70 cm spacing along track. NASA is predicting that, after full post-processing, *changes* in elevation can be measured to a precision of about a quarter of an inch. ICESat-2 acquires data from all over the Earth's surface, but the polar regions are of special interest as we worry about our changing planet.

The launch was preceded by several events, most of them open to the public, in Solvang and Lompoc, small towns just east of Vandenberg. The commitment, as well as the brilliance, of the NASA scientists shone through and it's worth remembering that some of them have devoted ten years—a substantial part of their working lives—to ICESat-2. I bumped into an ebullient Marcos Sirota, CEO of Sigma Space, in the hotel after one of the presentations. The joy, seen on NASA TV, as the United Launch Alliance Delta II launch vehicle erupted from its pad, was palpable and easy to share. The launch had been delayed a few days as some critical team members had been in Florida for the launch of the Parker Solar Probe. There was a further short delay during countdown, as the team waited for the temperatures of some of the chemicals on board the launch vehicle to fall within the required window. Finally, the "Go ICESat-2" decision was made. This was the 155th successful launch of the Delta II, which entered service in 1989, but also its last as it is being superseded. What a privilege to be there. The process in the minutes after launch was a complex one, with various parts of the launch vehicle being detached and several engine burns, until the separation, 79 minutes after launch, of the last of four cubesats, carrying sensors designed by universities. This unfolded on NASA TV as we were bussed back to the hotel and there was a flutter on board as each success was reported. ICESat-2 is a continuation of ICESat, which flew from 2003 to 2009, providing invaluable elevation data. NASA tried to fill the gap with IceBridge, a series of airborne missions, during the intervening years. The performance of ICESat-2, of course, is in a different world from ICESat, a manifestation of the spectacular developments in lidar itself: we have seen the single-photon approach enhance the airborne lidar environment, while incremental improvements in pulse rates and so on have been enhancing lidar for years. At the time of writing, the mission is proceeding according to plan: the satellite is orbiting as planned at an altitude of 496 km, the laser began operating about two weeks after launch, the ATLAS instrument is working well and elevation data of Antarctica was produced by 3 October.

Shortly after the above confirmation that NASA's budget is well spent and enables the most wonderful work, I moved rather closer to the ground, traveling to Las Vegas for the fourth Commercial UAV Expo, run by Diversified Communications ("DivCom"), which in 2017 acquired another UAV conference, Drone World Expo, with the result that the integrated event attracted 2350 attendees from 1300 organizations, all 50 states and 40 countries; and 168 exhibitors in a buzzing exhibition. The event was rounded out with workshops, a university roundtable discussion and ASPRS sessions. Once again DivCom ran a fine show, starting with outdoor demos on the Monday: not only did two of these feature VTOL aircraft—from AeroVironment and Autel Robotics—and the third, a C-ASTRAL aircraft that was launched from a catapult and landed with the help of a parachute, but the venue itself mattered. This was the Henderson Unmanned Vehicle Range, an initiative of Nevada Institute for Autonomous Systems (NIAS) and Nevada State College. Rather bare of vegetation, the site featured a strip of astroturf as a "runway", reminding me of a cricket pitch in the more arid parts of the world! After opening words from DivCom director Lisa Murray, there was a moment of silence to commemorate the first anniversary of the Mandalay Bay mass shooting on 1 October 2017 (DivCom announced a forthcoming



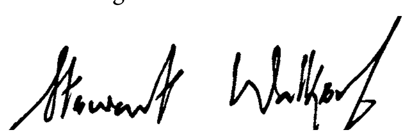
During the integration of Drone World Expo into Commercial UAV Expo, Diversified Communications sought the involvement of renowned UAV experts from international law firm Hogan Lovells. Here Lisa Ellman (left) engages in a plenary discussion with Michael Kratsios, Deputy Assistant to the President for Technology Policy, and Gretchen West (right) with Earl Lawrence, FAA's Director, Office of Unmanned Aircraft Systems Integration.
Images courtesy of Diversified Communications.

donation to Route91Strong). Chris Walach (NIAS) welcomed us and stressed safety. The state-of-the-art headquarters on site and the huge number of personnel in yellow jackets with radios, pick-up trucks, Humvees and so on, reinforced his message! There is plentiful evidence that initiatives to foster UAV activity bear fruit. Complementary examples came in two marketing pieces I picked up in the exhibition. One was a thick booklet from the Province of Alberta describing organizations involved in UAVs. The other was a leaflet from GGB[a] (Great Geneva Bern Area) in Switzerland, with concise explanations of its incubator role. The Swiss UAV concentration, of course, is well known and includes the famous Pix4D and senseFly companies, both now part of Parrot Business Solutions, which has acquired several companies and developed affiliations to others, such as MicaSense, in order to offer comprehensive solutions to its customers. Its well known eBee aircraft, however, still lacks the payload capacity for lidar—the same could be said for the Gateway/Trimble winglet that is now the Delair UX11. There were, of course, numerous big UAVs on show that can carry lidar easily and we hope to have articles on projects featuring some of these in the future. But it was intriguing that performance in terms of endurance seems to have taken off, with rather few suppliers reporting the 20-minute battery life that made us anxious only a couple of years ago. Better batteries are part of this—and the US-1 rotorcraft from Impossible Aerospace was presented as an aircraft built round the batteries (photogrammetrists will remember that this product name was the same as an analytical stereoplotter launched by Helava Associates at the 1976 ISP Congress in Helsinki!)—but other technologies are playing a growing role, for example high-performance chargers tuned to particular battery models, or solar, with lightweight, flexible panels suited to the upper surfaces of fixed-wing UAVs.

In a new feature of the conference, called "Pitch to the Press", we gentlepersons of the press scoured the exhibition to find interesting products, of which the most promising were selected and the suppliers invited to give five-minute pitches. A winner was chosen and DivCom issued a press release. This was eclectic but fun. On the other hand, couldn't the format of the product previews on the Monday afternoon, which are invaluable but rather an endurance test, with two parallel four-hour sessions consisting of 15-minute presentations from 32 vendors, be freshened and shortened?

You may remember the LIDAR Leader Awards from last year, run jointly by *LIDAR Magazine* and Diversified Communications, where we had more than 80 nominations, gave three awards and fomented a new impetus. This year we've added two new categories, for innovation and university achievement. Again the nominations are flowing in.

We began this note with ICESat-2 and its detector array. To put this in perspective, it is a tiny component of the payload propelled into space that day from Vandenberg—but its performance is essential to mission success. In a similar vein, an article caught my attention recently: Hank Hogan, on the editorial staff of *Photonics Spectra*, penned a short piece on remarkable ongoing improvements to filters and cited their importance not only to imagery but to automotive lidar, for which the requirement is narrow filters with flat tops and the highest possible transmission[1]. We can all see the continuous advances in the information generated from lidar systems. Sometimes it is salutary to reflect on the scientific brilliance, as well as persistence, behind the small as well as the large components that make the breakthrough.



A. Stewart Walker // Managing Editor

1 Hogan, H., 2018. Better filters yield better sensor performance, *Photonics Spectra*, 52(8): 34-38, August.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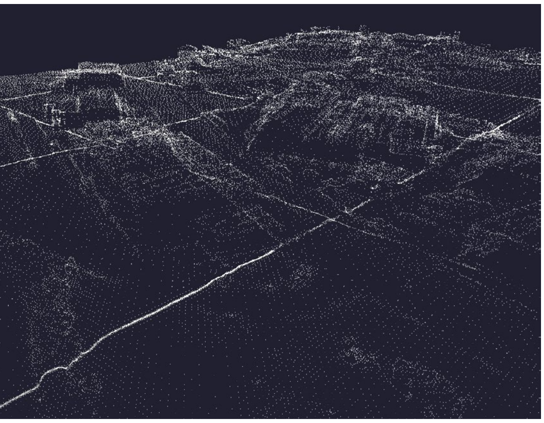
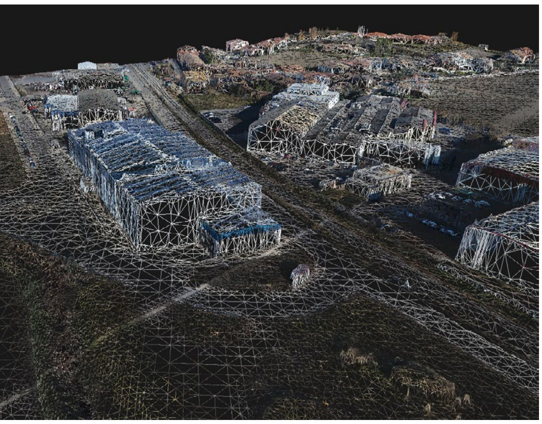


Inpho v9 DensePointCloud



Inpho v9 MESH

Inpho v9 TexturedMESH

Trimble Inpho Software Suite Extends Photogrammetric Deliverables for Broad Range of Geospatial Applications

Two New Capabilities Increase Flexibility for Photogrammetrists Generating Highly Accurate Deliverables

Trimble has announced a new version of its Inpho office software suite for photogrammetry. The suite includes two new capabilities:

- MATCH-3DX software for the creation of rich 3D point clouds and true orthomosaics
- MATCH-3DX Meshing add-on for the generation of photorealistic textured meshes

The announcement was made at INTERGEO 2018, the world's largest conference on geodesy, geoinformatics and land management.

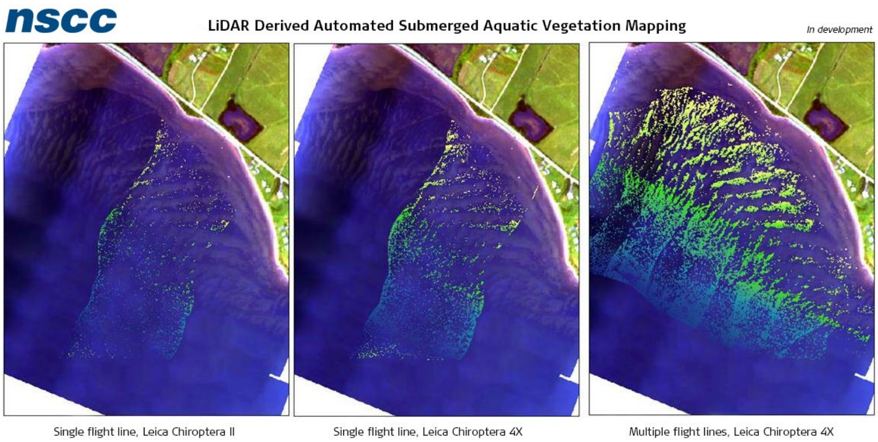
Inpho version 9 combines the classical photogrammetric capabilities of the existing MATCH-T DSM product with modern 3D workflows. The addition of the new products, plus continued enhancements, further establishes Inpho as a comprehensive software suite available for the production of photogrammetric-based deliverables.

The new MATCH-3DX software incorporates state-of-the-art **Semi Global Matching** (SGM) techniques that enable photogrammetrists to reach a new level of quality and precision when generating large scale point clouds and true orthophotos from aerial (frame) images. Through the high resolution data sets, photogrammetrists can more clearly identify edges of surfaces, such as building corners and roof lines, enabling the extraction of highly precise measurements, CAD objects or Digital Surface Models (DSM). The new **True Orthophoto** capability ensures that each image pixel is directly related to the terrain height, simplifying mapping and the overlay of GIS data, especially for urban mapping applications.

With the new MATCH-3DX Meshing add-on, photogrammetrists can generate highly accurate, **photorealistic textured meshes** that enable non-professionals to easily navigate and understand the real world environment. The 3D textured meshes provide an efficient data type for use within industry leading GIS systems and web-based 3D visualization services—often used for 3D city modeling, construction simulation and gaming applications.

"Inpho version 9 combines both classical photogrammetric processing with new true orthos and photorealistic textured mesh deliverables, all in a single software environment," said Tim Lemmon, marketing director of Trimble Geospatial. "Photogrammetrists can take advantage of the streamlined workflows and reduced training costs while having the ultimate flexibility to choose the workflow and deliverables best suited to their client's needs."

Trimble Inpho version 9 is expected to be available in fourth quarter of 2018 through Trimble's Geospatial Distribution Partners. For more information, visit: trimble.com/Inpho.



Comparison of LiDAR derived automated submerged aquatic vegetation mapping.

Leica Geosystems Increases Efficiency with Hydrographic Survey Systems Upgrade

New Leica Chiroptera 4X, Leica HawkEye 4X save more than 50 per cent in flight costs

Leica Geosystems, part of Hexagon, announced today the availability of Leica Chiroptera 4X and Leica HawkEye 4X. The latest upgrades introduce a new bathymetric LiDAR high resolution technology that increase the bathymetric point density by a factor four.

The higher point density allows customers to deliver high resolution products at reduced operational costs. Flight cost savings of 50 per cent can be achieved for typical bathymetric LiDAR end user specifications. The depth penetration increases up to 10 per cent with the new technology while not affecting the turbid water performance or accuracy.

Nova Scotia Community College is validating the new Chiroptera 4X bathymetric high-resolution technology in test projects on Canada's east coast in turbid water conditions. "The four times increased resolution dramatically improves our ability to detect objects, even on the scale of features 1 metre by 1 metre where the increased number of points can be used to further clarify the objects location and details. For vegetation mapping, the increased resolution of the sensor provides us an unprecedented level of detail related to vegetation and other materials on the seafloor. We have also detected new seabed features not discovered from previous bathy LiDAR surveys in the same area, which indicates an increased sensitivity of the solution," said Tim Webster, research scientist, Applied Geomatics Research Group (AGRG) Centre of Geographic Sciences (COGS), Nova Scotia Community College.

The 4X technology is available as an upgrade package to all current Chiroptera II and HawkEye III customers and will be integrated in all new bathymetric LiDAR systems. The improved resolution, depth penetration and accuracy provide substantial benefit for environmental and coastal monitoring, inland waters mapping, infrastructure planning, and near-shore applications.

Maximising efficiency

Typical end user specifications require two to four points per square metre for the highest quality level shallow bathymetric LiDAR data. This is easily achieved with a single flight line with the new Chiroptera 4X or HawkEye 4X shallow channel, while in previous generation double coverage was needed. This improvement saves half of the flight costs alone.

With the depth penetration of 2.7/k and collection of 140,000 points per second of the Chiroptera or HawkEye shallow channel, the new 4X technology offers an unmatched shallow water performance in respect to point density, turbid water performance and depth penetration. For the HawkEye deep channel, the 40,000 points per second collection is market leading in the industry and can easily deliver IHO order 1B data from single flight line.

"Optimising a bathymetric LiDAR system has always been a trade-off between sensitivity (depth penetration) and resolution. Our new 4X high-resolution technology allows us to improve both those parameters without any tradeoffs," said Anders Ekelund, Hexagon's Geospatial Content Solutions vice-president of Airborne Bathymetric LiDAR. "Performing advanced high-density site surveying allows users to extract better details for both above-water and underwater features, increasing our knowledge of coastal and inland waterways and habitats."

For more information, please visit: leica-geosystems.com/products/airborne-systems/bathymetric-lidar-sensors

Kaarta Announces Stencil 2 Mobile Mapping System

Raising the bar for rapid, high fidelity 3D capture and processing

Frankfurt, Germany | Intergeo—Kaarta, innovator of real-time 3D reality capture, today announced Stencil® 2, the next generation of its popular real-time, high fidelity 3D mobile scanning and generation system. Stencil 2 improves mapping accuracy and workflow with a new User Interface, GNSS localization, upgraded hardware, Confidence Metrics, and enhanced software intelligence.

Stencil 2 makes real-time operation easy, organized, and intuitive with a new user interface and on-screen keyboard giving users better control over scanning operations, parameter input, and file management. Stencil 2 ships with an iPad tablet to access operations and view real time scanning on the fly.

Stencil 2 records GNSS data for use in loop closure to georegister and geolocate datasets, correcting for drift and further improving the fidelity of large area scans. Kaarta offers an optional GNSS Kit with Emlid Reach RS+ RTK GNSS receiver and custom mounting bracket. Alternatively, Stencil 2 integrates with other NMEA 0183-compliant GNSS systems.

A host of Stencil 2 hardware upgrades include a faster processor, full size HDMI connector for a more robust connection to monitors, and double the on-board storage capacity providing storage for more scans and reducing the need to frequently offload files.

At the heart of Stencil 2 is Kaarta Engine, Kaarta's patent-pending advanced 3D mapping and localization algorithms. Kaarta Engine's proprietary approach reduces the drift error of alternative SLAM systems by an order of magnitude.

Kaarta Stencil 2 mobile mapping system

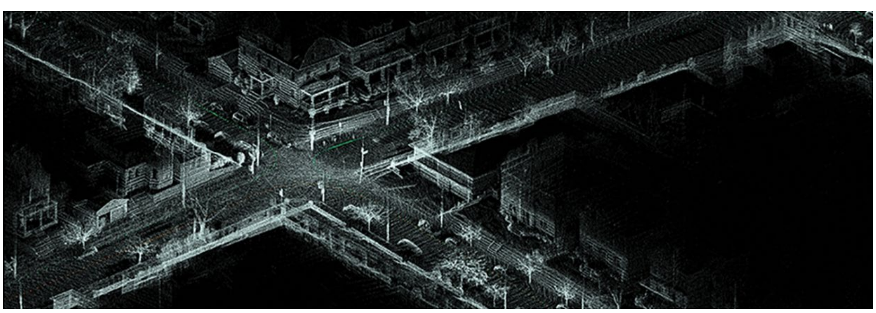
Confidence Metrics provide immediate feedback on the quality of scans by signaling whether new scan data is registered properly in the existing map, estimating the likelihood of errors and allowing the user to increase the level of confidence by adjusting data collection techniques or adjusting parameters.

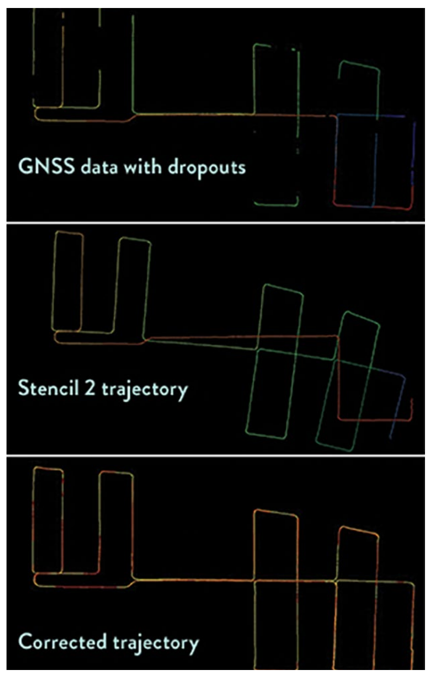
Stencil 2 incorporates Kaarta's latest intelligent mobile mapping advances. Automated Floor Leveling/Sectioning algorithms identify floor structures and smart-scan leveling for better scans and reduced post-processing time. Floor Planner automatically levels, rotates, and generates 2D images of a "slice" from a point cloud, generating 2D floor plans for large interior spaces such as warehouses or stores on the spot and eliminating many steps in the workflow.

Stencil 2 accurately maps exterior and large interior environments quickly and easily with a range of up to 100 meters and a data rate of 300,000 points per second up to 10Hz. Kaarta's integrated 3D mapping and real-time position estimation allow capabilities not possible with fixed-base scanning systems. Stencil 2 further solidifies the feasibility of mobile mapping as a stand-alone solution while also widening the possibilities of using mobile mapping to complement or augment other scanning methods.

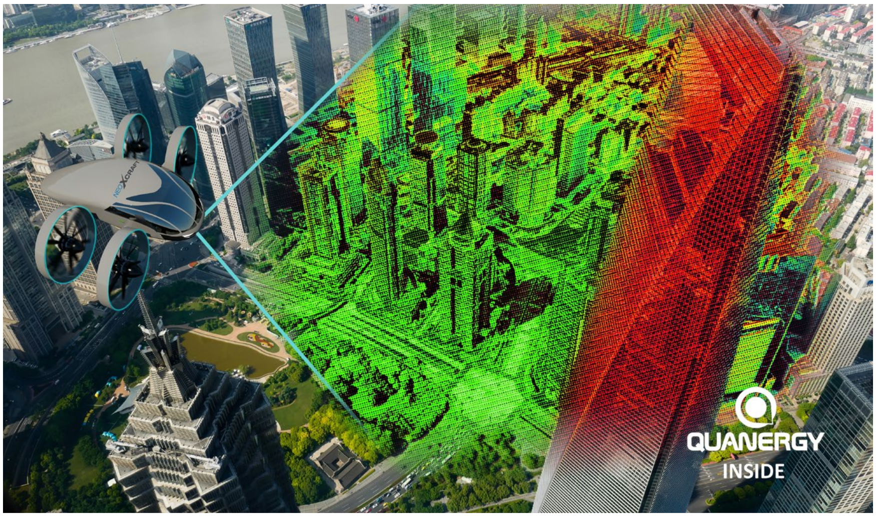
Stencil 2's ease of use, breadth of applications, and streamlined workflow make it the perfect choice for infrastructure inspectors, surveyors, engineers, architects, facilities planners, security personnel, or anyone who needs an easy way to document the 3D world quickly and dependably.

Stencil 2 is now shipping worldwide. Upgrade packages are available to current Stencil owners.


Three passes through an intersection correctly registered in post processing using GNSS in loop closure



GNSS in loop closure: GNSS data showing dropouts over the course of the data collection [top], trajectory data from Stencil 2 with some drift [middle], and corrected trajectory in yellow overlaid on the original GNSS data [bottom]



Quanergy Selected as Exclusive LiDAR Partner for VRCO

LiDAR manufacturer to provide S3 solid state LiDAR sensors to enhance safety of land, air, and water capable NeoXcraft XP2

Sunnyvale, Calif.—Quanergy Systems, Inc., a global leader in the design and development of solid state LiDAR sensors and smart sensing solutions, and VRCO, designer and manufacturer of the luxury high-end e-VTOL (electric Vertical Take-Off and Landing) craft, the NeoXcraft XP2, today announced that VRCO will exclusively use Quanergy's S3 solid state LiDAR sensors in the testing and market release versions of the aircraft.

The NeoXcraft XP2, which VRCO and the University of Derby unveiled in late 2017 and intend to launch in 2020, is a two-passenger e-VTOL high-speed land, air, and water capable craft. The craft can scan and memorize take-off locations and store the data for use on the next approach to the same location. Quanergy's innovative S3 solid state LiDAR sensor will be used for downward and forward scanning to enhance the craft's safety, providing the NeoXcraft with the ability to detect, sense, and avoid objects upon takeoff, approach and landing.

"VRCO is pleased with the support from Quanergy, and the use of the S3 LiDAR sensor provides a new level of enhanced safety for the NeoXcraft," said Michael Smith, chairman of VRCO. "Moving forward, all NeoXcraft will feature the S3 sensors as standard."

Quanergy's S3 is the first and only compact, low-cost, automotive-grade solid state LiDAR sensor, with the highest level of performance and reliability. Unlike its mechanical counterparts, the S3 uses optical phased array technology. This technology enables electronic laser beam steering for real-time scanning and situational analysis without any moving parts. The use of this specialized technology will further enhance the safety of the NeoXcraft during take-off and particularly upon landing when high precision is required, as is the case when landing on a superyacht.

"As the autonomous vehicle industry continues to evolve, it is imperative that all types of vehicles be equipped with technology that will give them the necessary level of awareness to keep passengers safe whether they are on the road or in the air," said Dr. Louay Eldada, CEO and co-founder of Quanergy. "Our S3 solid state LiDAR sensor will give the NeoXcraft the ability to accurately sense and perceive its surroundings while seamlessly integrating into the design of the craft."

In addition to its technical achievements, the compact design of the S3 enables the sensor to be concealed in the body of the NeoXcraft. This allows for real-time 3D mapping and object detection, tracking and classification, without compromising the aesthetics or aerodynamics of the craft.

To learn more about Quanergy's S3 solid state sensors, please visit go.quanergy.com/e/297232/s3-/bx86n/207604617.

FARO and STORMBEE Partner to Optimize Traceable Construction

Breakthrough Wide Area 3D Scanning Solution

FARO®, the world's most trusted source for 3D measurement and imaging solutions for Construction BIM and STORMBEE®, a pioneer in Mobile UAV technology, have partnered to offer an integrated, cost effective airborne 3D scanning solution specifically designed to optimize on-site capturing workflows as part of FARO's Traceable Construction™ constructionbim.faro.com/en/traceable-construction/. This integrated solution includes the best in class FARO Focus laser scanner and the STORMBEE S series UAV and BEEFLEX software suite.

Enhanced Productivity

The FARO—STORMBEE airborne solution enables wide area scanning missions, such as highway or train infrastructure, large construction sites and buildings as well as open pit mines. While these would take days when scanned from the ground, they can now be completed in just hours without interrupting traffic on in process construction work. Additionally, this airborne solution further enhances productivity by allowing users to capture complex environments, such as factories, chemical plants or other infrastructure features inaccessible to ground based scanning, from the air with exceptional levels of accuracy and detail and create as-built drawings, isometrics and facilitate analysis. The data can then download to FARO BuildIT Construction software to monitor construction quality control and progress or to easily create as-built CAD models with FARO As-Built Suite.

Optimized Resource Deployment

The user-friendly BEEFLEX software allows users to create centimeter level accurate point clouds directly from the in-flight data. Furthermore, the intuitive user interface assures that just about anyone can become a viable "expert" with no more than one hour of hands on training. Finally, BEEFLEX data can be exported directly into FARO SCENE software for further analysis and/or to combine aerial scans with the detail rich data from terrestrial scanners.

"STORMBEE has developed and validated its UAV credibility from real life testing in the most rigorous environments" explains Liesbeth Buyck, CEO of STORMBEE". As a result, we are confident that this turnkey solution, that includes the STORMBEE UAV and the FARO Focus laser scanner, creates a new reliability and quality benchmark for airborne 3D data capture solutions".

"FARO pioneered the Traceable ConstructionTM end to end value concept and continues to innovate the construction industry by optimizing end user experience and value", states Andreas Gerster Vice President FARO Construction BIM. "With the combination of the unique competencies of FARO and STORMBEE, we are now able to drive a new level of time and cost effectiveness for wide area 3D data capture for large construction projects or projects where terrestrial based scanning is not the most viable option".

For more information: constructionbim.faro.com/en/traceable-construction/on-site-capture/

Creaform's Pipecheck Software Brings Surface Corrosion Assessment to Full Pipe Joints

New Pipecheck 5.0 offers faster analyses and reports for pipes of up to 60 ft

Lévis, Québec—Creaform, a worldwide leader in portable 3D measurement solutions and engineering services, announced today the release of Pipecheck 5.0, which features major enhancements enabling integrity assessment for full pipe joints. Since its introduction in 2011, Pipecheck has become established as the standard for providing accurate and reliable NDT surface damage diagnostics on both the inner and outer linings of pipes, using both ultrasonic testing and 3D scanning, whether for corrosion, dents or gouges in the metal.

Enhanced weld to weld inspections:

- **Full-pipe joint assessment of up to 60-foot pipes:** Surface inspection of industry–standard pipe joints up to 56 inches in diameter.
- **Faster analysis and reporting:** On-site analysis and reporting up to 6 times faster.
- **Enhanced workflow:** Data analysis is performed in sections and analyzed together to produce a single comprehensive final report, so pipeline owners have crucial information they need to act quickly.
- **Multiscanner capability:** Divide inspection time by the number of scanners used to ensure faster total inspection time.
- Other key competitive advantages of the Pipecheck solution include reliable and repeatable measurements that are independent of the operator's or the technician's skills.

A Game Changer in Pipelines Surface Inspections

"The challenge wasn't only to increase Pipecheck's capability as far as pipe lengths, but also to improve the speed of the analysis and reporting, regardless of a pipe's size," says Steeves Roy, Creaform Product Manager. "With no compromise on the speed of data processing, analytics, and reporting, Pipecheck 5.0 now becomes the most trusted full-pipe joint assessment solution on the market. All Pipecheck license owners already in the field and covered by the Creaform Customer Care Program will benefit from this major software upgrade."

"Most asset owners and NDT service companies are turning to Pipecheck for pipeline corrosion mapping and assessment. What is key for our customers is the accuracy and repeatability of 3D mapping compared with manual measurements, as customers need to make the safest decision regarding a pipeline's integrity," adds Mathieu Magnan, Business Development Manager at Creaform. "Inspections that used to take days can now be performed in only a few hours with direct on-site reporting using Creaform technologies. With Pipecheck 5.0, it is now possible to scan, analyze, and report data from a full pipe joint in less than a day. This is a major performance leap forward compared with previous versions of the software."

MX3D Printed Bridge at DDW by Adriaan de Groot

Project Update: World's First 3D Printed Steel Bridge

Amsterdam based startup MX3D has finalized its 3D printed steel bridge. The project is still ongoing, the smart bridge project (with stability tests) will last over the next 2 years. For this they will regularly use the FARO Laser Scanner and BuildIT Construction software.

The Bridge, designed by Joris Laarman Lab, with Arup as lead engineering partner is now ready to be installed at its final location, *but* will first be on display at the Dutch Design Week (DDW) in Eindhoven, from October 20th till 28th 2018.

In addition to its unique construction, the bridge is also a living laboratory for data scientists. It is instrumented by Autodesk, Force Technology, Imperial College London, Lenovo & HBM with an innovative sensor network. Data obtained from the sensors visualize intelligence about bridge traffic, structural integrity, and the surrounding neighborhood and environment. During the DDW visitors are invited to walk over the bridge to generate the first data set. Data from the bridge will be used by partners like The Alan Turing Institute, the UK's national institute for data science and artificial intelligence, along with Autodesk to build a digital twin model and sensor network which use advanced data analysis to monitor the bridge's performance in real-time. The work on this 3D printed bridge will contribute to the future of safe, efficient and data-driven engineering by monitoring the structure as thousands of people and bicycles traverse the bridge hourly once in place.

Arup, the project's Lead Engineer, and researchers from The Alan Turing's Data Centric Engineering Programme (a consortium of researchers from Imperial College London and the University of Cambridge) have performed a successful load test of 10+ ton this September. Comparisons between predictions from computer models that the team have developed with the results from this test will be made to demonstrate the load carrying capacity of the bridge and provide invaluable structural performance data.

SMART BRIDGE

The consortium of mathematicians from The Alan Turing Institute have teamed up with MX3D to deploy a smart sensor network to develop a new data centric engineering approach for 3D printed structures. Arup, Imperial College, Autodesk and Force Technologies are actively involved in the design, install and use of the sensors network.

These sensors will collect structural measurements such as strain, rotation, load, displacement and vibration, and will measure environmental factors such as air quality and temperature, enabling engineers to measure the bridge's health in real time and monitor how it changes over its lifespan. This data will also allow us to "teach" the bridge to understand what is happening on it, how many people are crossing it and how quickly.

The data from the sensors will be used as input for a 'digital twin' of the bridge, a living computer model that will reflect the physical bridge with growing accuracy in real time as the data comes in. The performance and behaviour of the physical bridge can be tested against its digital twin, which will provide valuable insights to inform designs for future 3D printed metallic structures and ensures it is safe for pedestrians under all conditions.

Pivots

Like all innovative projects the MX3D bridge project required several pivots. The initial design for the 12 meter metre bridge has changed significantly. Based on material research and structural testing Arup and Joris Laarman Lab created a structural design strategy. This led to the final bridge design by Joris Laarman Lab in early 2017.

In March 2017, the printing and assembly of large segments of the bridge began. In parallel MX3D engineers have continued working on realizing their vision of robots autonomously 3D-printing infrastructure. Last summer, a robot was placed on the bridge. It validated the company's vision and confirmed that robots will be able to print bridges without human intervention.

FACTSHEET

Location Bridge: Oudezijds Achterburgwal, at the crossing with the Stoofsteeg located in the Red Light District of Amsterdam.
Technology: MX3D, Proprietary Software
Client: City of Amsterdam
Designer: Joris Laarman Lab
Lead Structural Engineer: Arup
Material & Structural Analysis: Imperial College London
Material Expert: ArcelorMittal
Research: AMS-3D Building Fieldlab, Amsterdam Institute for Advanced Metropolitan Solutions
Digital Tools: Autodesk
Digital Twin: Alan Turing Institute
Sensor Network Design & Install: Force Technology & Autodesk
Scanning: Faro Technologies
Construction Expert: Heijmans & Mous
Hardware, computing: Lenovo
Hardware, robotics: ABB
Hardware, Sensor Network: HBM
Hardware, welding: Oerlikon
Hardware, air cleaning: Plymovent
Welding Gas: Air Liquide
Material: Stainless Steel
Length: 12.2 meter
Width: 6.3 meter
Height: 2.1 meter

HxGN Content Program is Now Available Through GSA

Federal, state, local government agencies can now purchase high-resolution aerial imagery directly through GSA

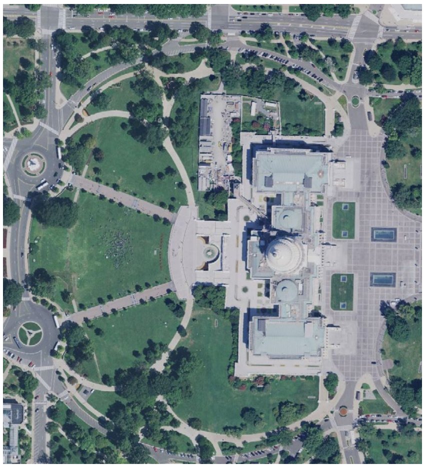
Hexagon's Geosystems Division, the smart digital realities provider, announced today the HxGN Content Program's imagery is now available to government agencies directly through the General Services Administration (GSA).

Government agencies at the federal, state or local levels can now purchase high-quality aerial imagery content via subscriptions to a streaming service or physical pixel delivery for download. The imagery content is available directly in the application of choice through Open Geospatial Consortium (OGS), Web Map Services (WMS) and Web Map Tile Service (WMTS) protocols. The professional four-band (RGBN) orthorectified 15- and 30-centimetre imagery content meets conventional mapping accuracy requirements enabling use in many applications that in the past were only serviced by contracting for such products.

"Enabling our government customers to purchase directly through GSA offers a fast, flexible and cost-effective procurement solution to meet operational challenges," said John Welter, Hexagon's Geospatial Content Solutions president. "With a significant increase in demand and continual refresh of the imagery content, we wanted to ensure it was easily available through our new offering with GSA."

Quality control by experts

Launched in June 2014, the HxGN Content Program provides valuable geospatial content and delivers professional-grade airborne images captured with Leica Geosystems' airborne sensors, including enhanced-resolution, four-band orthos and stereo imagery. The imagery data is processed by experienced photogrammetry professionals using the latest processing technology to meet conventional mapping standards and deliver an exceptional product. Independent quality control is then performed to ensure accuracy specifications are achieved.



Hexagon announces HxGN Content Program imagery is now available directly through the General Services Administration (GSA). Imagery, such as this aerial capture of the Capitol Building in Washington, D.C., USA, can be downloaded or streamed for purchase from GSA.

The imagery content is refreshed on a regular schedule of no more than two years, and data capture of entire states is done within one flying season. Current coverage includes the entire continental U.S., Puerto Rico, and portions of Canada and Europe.

To view the most current status of the HxGN Content Program's data availability and acquisition, please visit hxgncontent.com and follow us @HxGNContent.

A full list of HxGN Content Program ortho-rectified aerials are available through GSA at gsaadvantage.gov/advantage/s/search.do?q=0:2HXIP&db=0&searchType=0

SIGMA SPACE Brings Single-Photon to Hexagon

A Further Tale of People, Acquisitions and Technology

In our July issue, managing editor Stewart Walker gave a lengthy account of the development and status of airborne lidar systems at the Leica Geosystems and Sigma Space subsidiaries of Hexagon. This was drawn mainly from an interview with Ron Roth, Product Manager—Airborne Topographic LiDAR for Hexagon's Geospatial Content Solutions. The discussion touched on the addition of single-photon technology to Hexagon's portfolio—and that's where the article ended—but then Stewart spent time with founder and CEO of Sigma Space, Dr. Marcos Sirota, after which Ron hosted a tour of the assembly and test areas of the production facility in Lanham, Maryland. This is the sequel, therefore, and describes what Stewart discovered at Sigma Space.

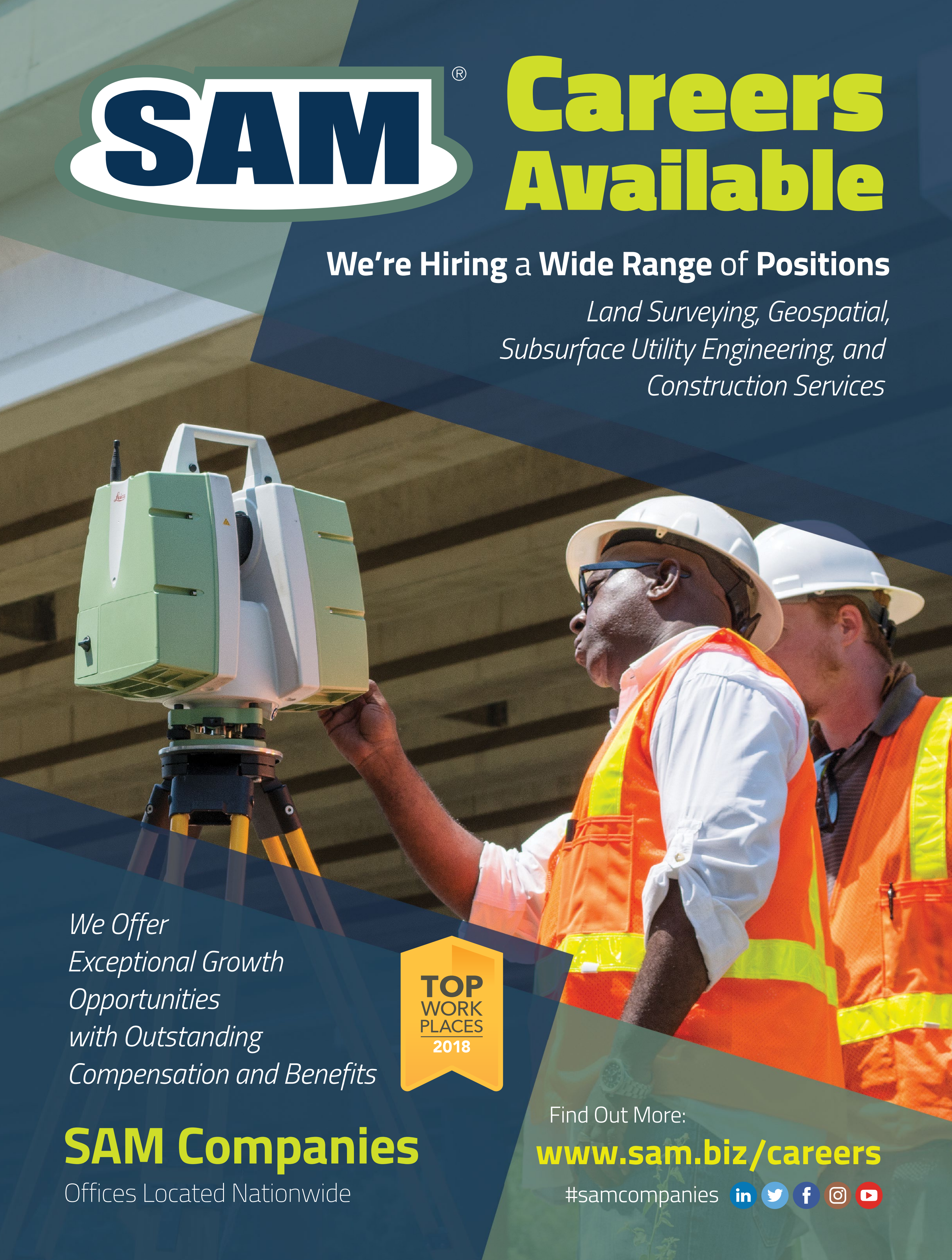
Single-photon: setting the scene

Sigma Space's Single-Photon Lidar (SPL) technology has been well reported in these pages before, by Dr.

Dr. Marcos Sirota, founder and CEO of Sigma Space.

Above: SPL100 Lidar data colored by RGB imagery from RCD30. Flown at nominal operational altitude, 12,500 ft, over Easton, Maryland with 50% line overlap.

BY DR. A. STEWART **WALKER**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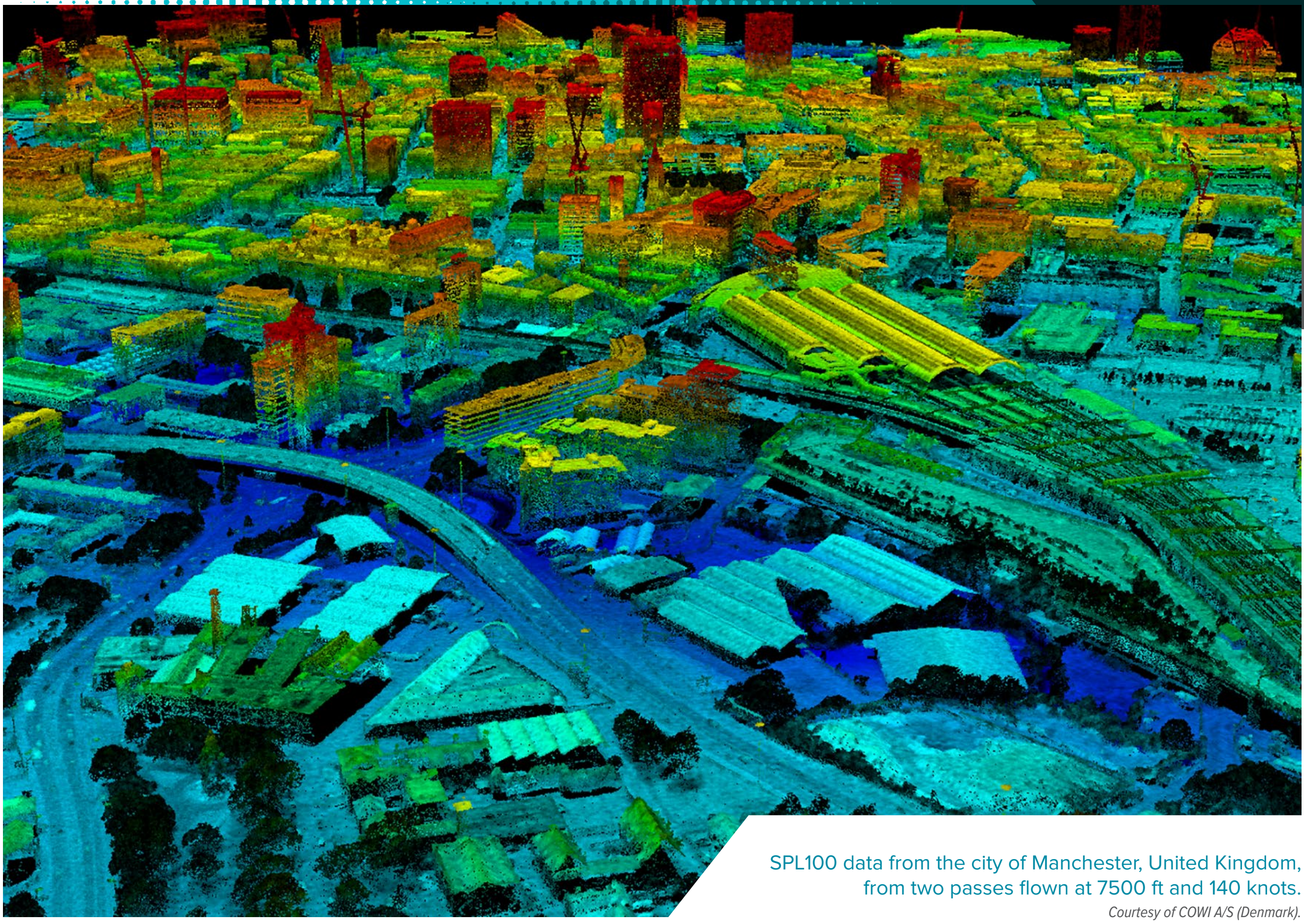


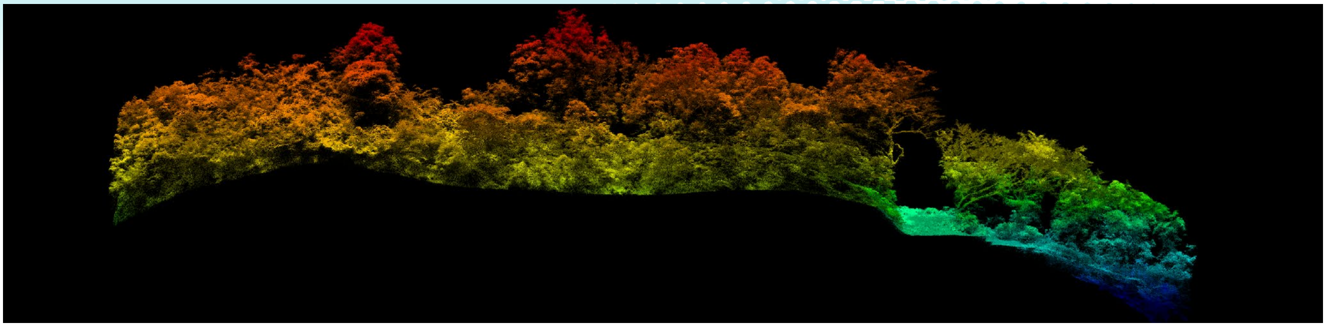
SPL100 data from the city of Manchester, United Kingdom, from two passes flown at 7500 ft and 140 knots.
Courtesy of COWI A/S (Denmark).

Stephen Mitchell[1], formerly director of mechanical engineering at Sigma Space and now with University of Maryland College Park (UMCP). At the time of my visit the ATLAS sensor for the NASA mission ICESat-2 had passed its tests at NASA Goddard Space Flight Center (GSFC) and was on its way to Gilbert, Arizona, for integration on to the spacecraft by its constructor, Orbital ATK (now Northrop Grumman). The launch took place on 15 September 2018 and *LIDAR Magazine* was in attendance!

Ron summarized the motivation for the acquisition of Sigma Space as the potential to accelerate the commercial applications of SPL technology. The ongoing business of Sigma Space was focused on clients such as DoD and NASA. Sigma Space had many successful single-photon instruments in operation and a proven capability to construct operational instruments at low production levels. Leica Geosystems saw this as an opportunity.

The advance of linear-mode lidar is constrained in some ways by eye safety. Using two lasers is not a reasonable solution. It is not possible merely to fly at the same altitude and increase laser power to achieve higher pulse rates without suffering consequences in eye safety due to that increased output. If it is not possible to use more power, an alternative is to increase the size of the receiving optics, but this increases the size and weight of the airborne system. The better solution is to increase the sensitivity of the receiver, with the result that the pulse rate can be increased without requiring more power. This is where single-photon comes in—the receiver can detect as little as one arriving photon. The Leica TerrainMapper, for example, which is the latest model in the linear-mode lidar product range, uses a 20W laser to acquire 2 million points per second, i.e. 2 million effective laser shots per second (2 MHz). The ALS80 uses a similar 20W laser at 1 MHz effective pulse rate. The SPL100, however, obtains 6 MHz effective pulse rate from a 5W laser. The innovative underlying technology, through breaking up a single laser output into 100 beams, is capable of a pulse rate three times greater than that of TerrainMapper with one quarter of the laser power, i.e. is more than an order of magnitude more sensitive on the receiving end, giving extremely high effective pulse rates from a relatively

1 Mitchell, S.E., 2015. Why not see the forest *and* the trees? *LIDAR Magazine*, 5(4): 31-35, June.



SPL100 data sample over a densely forested area in the island of Hawaii.

small laser[2]. Leica Geosystems appreciated the market requirement and knew that Sigma Space had the know-how.

I asked Ron about the other exciting new lidar technology, Geiger-mode. He replied that, like single-photon, it uses a 2D array of detectors. However, unlike Geiger-mode, single-photon acts more like an array of linear-mode systems, making range measurements to intercepting surfaces at multiple ranges from a single output laser pulse, whereas Geiger-mode is limited to a single return per pixel per laser pulse. In order to overcome this limitation, Geiger systems work in a "photon starved" mode, with a very low probability of detection per pixel per pulse, and rely on dramatic repeat-sampling to separate signal from noise and improve accuracy. Leica Geosystems perceived that single-photon was a superior technology and pursued it. It recognized opportunities for using the technology in wide-area acquisition, for example for the HxGN Content Program.

2 This remarkable result of leading-edge physics and engineering has been described in many articles, for example: Roth, R. and M. Sirota, 2017. The evolution of lidar, *GIM International*, 31(2): 37-39, February.

I invited Ron to explain the implementation of single-photon technology in the SPL100 in more detail. One of the great advantages of SPL systems is a very short detection reset time, or minimum return separation in terms of vertical distance, which currently permits 24 cm range discrimination between separate targets. This is similar to that of the latest linear-mode systems, though better than the ALS80, for which the corresponding figure is >1 m. It is very suitable for acquiring the ground in low-brush—on a par with the full-waveform linear-mode systems. This makes single-photon technology very competitive. Ron repeated that Geiger-mode is limited by significant amounts of repeat looks at the same target and setting low detection probabilities of perhaps 35% or less. That means a probability of only 35% of detecting a returning photon: sensing all the vegetation as well as the ground is challenging without considerable repeat-sampling.

Ron enthused over single-photon being analogous to 100 linear-mode systems in parallel. I probed further by asking whether single-photon technology can provide intensity values. Ron explained that multiple photons from a single return produce a wider pulse at the detector. It is possible to time the leading and trailing edges of the incoming signals. Intensity is derived from the return pulse width and Sigma's SPL timer is capable of resolving the leading and trailing edges of each return with 80 picoseconds (ps) resolution.

The wavelength of the laser in the SPL100 is 532 nanometers (nm), though others are possible. This is partly historical: earlier generations of photomultiplier arrays, which were used in early products, had peak sensitivity in the visible. One advantage of 532 nm is water penetration, but as yet there are no algorithms in the SPL100 software to exploit this, e.g. water surface detection, refractive ray bending, speed of light change, so the system is not targeting bathymetric applications. Moreover, the SPL100's canopy penetration is rather good. Some of the earliest single-photon systems were designed for that: it behaves like a multi-return linear-mode lidar for detection of forest floor. We moved on to geometric accuracy: delivered data, after calibration and registration, is stated to be in the 5-10 cm accuracy range in terms of $RMSE_Z$. Leica Geosystems has made amazing progress in terms of achievable accuracies. The point density, usually measured in points per square meter (ppsm), is based on effective pulse rate, flying height, flight speed, wedge angle etc., allowing users the flexibility to tailor operating settings (within limits) to the point density requirements.

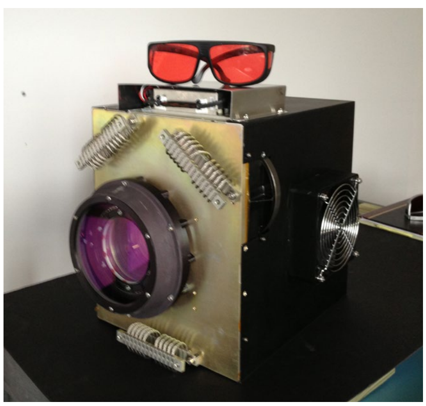
The SPL100 was not fully productized by Sigma Space at the time of acquisition. Thus re-engineering began immediately. Leica Geosystems approved the building of several units as part of productization. The sales network and content programs were activated in a "controlled rollout" mode for the SPL100, while experience was being gained. Existing Leica Geosystems components were integrated into the system, e.g. PAV100 gyro-stabilized mount, RCD30 medium-format frame camera, FlightPro software for mission execution, and MissionPro software for mission planning. Collectively, these Leica Geosystems components are known as the Common Sensor Platform, including pilot display, operator display, GNSS/IMU, data logging, and stabilized platform. The SPL100 is built in the Sigma Space facility in Lanham, whereas the Common Sensor Platform comes from Heerbrugg, Switzerland, where products such as the ALS80 and TerrainMapper are manufactured.

Leica Geosystems is transitioning the SPL100 into a fully commercialized system and is conducting pilot projects with partners, e.g., Woolpert in South Dakota early in 2018, and sample projects in Europe, e.g. the region of Navarro in northern Spain. Ron estimated that these systems are a minimum of 3x, but more likely 6-10x, as productive as linear-mode, which can achieve 2 MHz only up to certain flying heights. Woolpert, which has a long history of working with Leica Geosystems and Sigma Space, flew the SPL100 in Hawaii, where it performed well over lava fields with relatively low reflectivity.

As we neared the end of the session, I asked Ron to speculate on the value of single-photon technology for TLS or MMS systems. He felt there could be some. He said one company makes a single-photon lidar for UAVs—so small units for terrestrial use should be feasible. There's no particular reason why the technology can't be miniaturized.

The story of Sigma Space

I joined Marcos in his office to talk about Sigma Space and its history. The company was founded in 1997 to make optical instruments for aerospace. It began with the NASA ICESat mission, which carried a linear-mode waveform lidar. Born in Argentina, Marcos completed his PhD at the University of Washington in 1989, went to NASA as a post-doc, then worked at GSFC and University of Maryland Baltimore County. Sigma Space's operations began in April 1998. His aspiration was not a classical service supplier but a company that created technology. He perceived a void amongst NASA suppliers for constructing and designing systems from proof of concept technical readiness level 6 (TRL6: a technology is usually tested in aircraft before it is used in space). His idea was an engineering development company working in cooperation with NASA. Sigma Space started to work on single-photon sensitive technologies early on, first on an airborne lidar for the measurement of cloud physical properties with Dr. Matthew McGill, and, soon after, on the commercialization of the Micropulse Lidar, a ground-based instrument to measure cloud and aerosols, developed by Dr. Jim Spinhirne. Dr. John Degnan, who became Sigma Space's chief scientist in 2003, was at NASA at the time, and Sigma Space worked with him on the first single-channel and four-channel



Left: Miniature Airborne Topographic Mapper (Mini-ATM). Altitude: 2000 to 6000 ft AGL

Below: Viking 300 UAV platform. Customer: NASA Wallops

NASA Goddard's Multiple Altimeter Beam Experimental Lidar (MABEL) mounted in nose cone of NASA's ER-2 (shown right). Flew at 65,000 ft to validate algorithms for ICESat-2.

Lockheed ER-2 #809 high altitude research aircraft in flight.

NASA Photo by: Jim Ross

single-photon terrestrial altimeters. A patent was filed and a license exists today. GSFC launched the Mercury Laser Altimeter (MLA) in 2004. At the time the laser altimeters going to space were conventional, single-channel (i.e., just one beam), linear-mode lidars.

Sigma Space's first success for their technology was a USAF Small Business Innovation Research award, for a 100-beam system (not unlike the SPL100) capable of operating at 3000', which flew in 2006. Marcos had a very good electronics group, which designed the timers, truly the core of the instrument, and the result was a resounding success according to the Air Force Research Laboratory (AFRL) program manager, Richard Richmond. They found a plane nearby: UMCP had an aircraft with a hole for a sensor, since it had been testing instruments for USAF. Sigma Space flew and tested the instrument rather ahead of the schedule expected by the more formal AFRL. USAF, GSFC and UMCP were all very enthusiastic about the results. The system, known as Leafcutter, was later flown over both forest and ice, for example over Greenland, the data going to NASA. The University of Texas purchased a copy of the system for its Antarctic campaigns. After Leafcutter came Mini-ATM for NASA to monitor Greenland's ice sheets, intended to fly in a UAV. There were also various scientific instruments, mainly for NASA, which were not lidar but contributed to the intense build-up of expertise in the company.

A current version of the technology was selected for the instrument for ICESat-2—SPL is in space! The instrument is the Advanced Topographic Laser Altimeter (ATLAS), which has six beamlets. To create datasets similar to those to be measured in space, Sigma Space collaborated with NASA to build an instrument called Multiple Altimeter Beam Experimental Lidar (MABEL) for tests on the ER-2 aircraft at 65,000', sufficiently high to have most of the atmosphere below the aircraft. The first of these flights was in 2010. MABEL was a GSFC project, but Sigma Space was very involved, providing electronics, mechanical assembly and more. A fundamental component of the instrument for ICESat-2 is the timing electronics, developed by Sigma Space. In addition Sigma Space provided the opto-mechanical components for, and built in-house, the laser pointing and boresight determination system, the ATLAS Laser Reference System. The principal investigator for the ER-2 mission was Dr. Matthew McGill. The project scientist for ICESat-2 is Dr. Thorsten Markus.

Marcos and I very briefly talked about automotive applications, but returned quickly to aerospace. Around 2011, Marcos decided to go for something more powerful than Leafcutter, upgraded for higher altitude, so Sigma Space built the HRQLS-1 (pronounced "hercules"), capable of operation at 7000' with 50 cm pixels, giving a density of 8 ppsm in a single pass. This was used, for instance, for a Connecticut collect for

Left: HRQLS (High Resolution Quantum Lidar System). Altitude: 6,000 to 10,000 ft AGL. Platforms: King Air 90 and B200.

Above: The Beechcraft King Air 250
Image courtesy Textron Aviation.

USGS, flown in 2015. The purpose was the validation of the technology for the USGS 3DEP program.

Also, around 2011, Sigma Space worked with Woolpert to design and engineer a High Altitude Lidar (HAL) system for use at altitudes greater than 25,000'. Although Sigma Space SPL systems were operating at only 3,000' when it initially become involved in HAL, the company saw that the high altitude system was feasible and signed up to build it. A requirement for this project was that the system had to be mountable in a wing pod, restricting form factor and mass. Ultimately, the system was tested and achieved initial operating capability (IOC) status after hundreds of hours of flight testing and the development of two prototypes. As a result, Sigma Space has built five instruments, three in the same configuration as the first, and two under Leica Geosystems, named the SPL100HA, which is similar to the commercial instrument, SPL100, but has a higher power laser so it works at higher altitudes. The two SPL100HA units were delivered in December 2017, capable of operating at 200 kts and up to 30,000'.

From HRQLS-1, Sigma Space advanced to HRQLS-2, still with 50 cm footprint spacing within the 10 x 10 array, but with a bigger laser to enable operation at 12,000', which offered advantages in terms of air traffic control. As they were finishing HRQLS-2, a positive report was announced by USGS on HRQLS-1. Sigma Space participated in the ILMF conference for three years and Leica Geosystems became interested in the new technology. The HxGN Content Program was a major driver, too. Today, the SPL100 is offered to partners as a tool for content generation. The partners can perform as much of the workflow as they want, for example flying and processing, or just flying. Sometimes Leica Geosystems flies the instrument itself, using Northwest Geomatics' aircraft, or a partner aircraft, or Dynamic Aviation, which also carries out many of the test flights of Sigma Space's DoD instruments.

Sigma Space was seeking a large partner to put the technology to greater use. Sigma Space had also considered data services, so there was a meeting of the minds between the two companies. The deal became a full acquisition, however, to satisfy stakeholders such as the workforce, which was very necessary both on the commercial side and for NASA work—there was no obvious dismemberment to fit the bill. Sigma Space was acquired in early 2016 by Hexagon as a subsidiary of Leica Geosystems. Recently, operation of Sigma Space was transferred to Hexagon US Federal, the arm of Hexagon doing business with the federal government and DoD. There is already a long history and much experience of defense work at Hexagon Federal, starting from the federal systems arms of ERDAS and Intergraph. Nevertheless, Sigma Space will continue to produce instruments for Leica Geosystems and develop commercial technology jointly with Leica Geosystems. Marcos is very proud of what has been accomplished.

I raised the issue of intensity values, just as I had with Ron earlier in the day.

Marcos explained that intensity, by definition, is the number of photons that return—what a linear-mode system records. Single-photon systems work with 100 beams that are like linear-mode but with fewer photons and much more sensitive detectors. Thus the returning signal does provide a measurement of intensity on a per pulse basis. By contrast, Geiger-mode has to do this by repeat-sampling: those systems have low probability of return. Only after the Geiger-mode system fires many shots at a particular point on the ground can it retrieve an "intensity" based on the number of returns versus number of pulses fired. But this is very processing-intensive. It is also very dependent on the GNSS/IMU accuracy.

I also asked about the bathymetric side and Marcos said there are export restrictions in play, depending on the capability of the system—bathymetric surveying has become very sensitive worldwide. Sigma Space has not developed any bathymetric capabilities or software. Bathymetry is also a difficult problem (what's happening to 100 beams under the water, both on the surface and in the water column, plus the refraction issues), so Sigma Space will refrain from this market unless Hexagon uncovers some unexpected market requirements. Also, Sigma Space is moving to use 1064 nm, so water penetration will no longer be possible, though this change will help for generating breaklines at the land/water interface. There would be some advantages in an even more radical change, to 1550 nm, but Marcos argued that this is not so good for some applications. So 1064 nm is a comfortable choice on both physics and engineering grounds. I similarly repeated my question on TLS or MMS possibilities. Marcos said there are some reasons to develop SPL for such applications.

> "Altitude does not affect timing accuracy. The accuracy of 3D points depends on the accuracy of both timing and geopositioning."

Does vertical accuracy remain the same as you fly higher? Marcos gave further explanation. Altitude does not affect timing accuracy. The accuracy of 3D points depends on the accuracy of both timing and geopositioning. As you fly higher, the vector is longer, so the results are directly affected by the performance of the GNSS/IMU system, but mainly in X and Y rather than Z. Timing is the biggest influence on Z. What influences timing? The length of the pulse of the laser is an important factor—the sharper the better—and is a function of the physics of the laser. There is jitter in the detector and jitter in timing. These factors are all the same at 25,000' as at 3000'. Thus the error source that is worst affected by increasing altitude is geolocation.

Sigma Space SPL timer resolution is 80 ps, but 2 ps has been achieved for a NASA project. And the next generation timer is in the making. Hexagon has a European partner which has demonstrated the SPL100 to acquire data for infrastructure. Demonstrations are necessary because the process to start a national campaign is long and complex. The data can be used for construction and engineering work. In these applications, much higher spatial resolutions could be helpful given the level of detail that could be requested. The recognition of types of trees, as in a recent Minnesota collect, would benefit from higher resolution too. Thus, much higher data rates or "points per second" are in the plans. With the spread of GPUs, moreover, processing costs will fall considerably. Sigma Space is also moving towards real-time processing.

We spoke about ILMF and its power as a platform for the proselytization of new technologies, attracting the best speakers on the development side as well as the professional. Marcos concluded our enthralling discussion with the comment, "It [ILMF] has achieved a very high scientific content." Yes, indeed.

On the shop floor

After lunch, Ron took me on a tour of the laboratory, where Bruce McCready showed me a system in the testing process. I noticed similarities to the ALS systems that I remembered from years ago, in terms of the rack arrangement and the complex wiring for power distribution, but of course the overall appearance was much more modern

SPL100 mounted on PAV100 gyro-stabilized platform. Complete flight suite including RCD30 camera controller and FlightPro units shown.

and sophisticated, including the Leica CC33 Camera Controller, GNSS/IMU and data logger. There is both flight planning and flight execution software. They still use a laptop to control the SPL100 sensor, because the sensor GUI is not integrated in the Leica FlightPro software, yet. Once it is incorporated, however, data will go straight to the Camera Controller, a useful simplification. Ron added that, while many ALS customers do not use a gyro-stabilized mount, all SPL100 customers do due to the higher flight altitudes.

A silver box on the sensor head contains the 5W laser, similar in physical size to the one used on the ALS80. While the standard SPL100 uses a 5-watt laser, the HAL and SPL100HA systems are designed for operation at greater flying heights and use a 15-watt laser. Ron pointed out that, while the lasers in linear-mode systems such as the ALS80 output laser pulses of 3 ns duration, SPL technology uses pulses as short as 100 ps. This simple comparison highlights the innovative nature of the Sigma Space technology.

End note

Ron returned to work and I spent the remainder of the day with Sigma Space scientist Claudia Carabajal, who works as a NASA contractor and has been heavily involved in ICESat, ICESat-2 and other missions. She took me on a memorable tour of GSFC, during which I saw instruments in testing as well as the workspace where the ATLAS instrument for ICESat-2 had successfully completed its tests before being shipped to Arizona. I met several brilliant NASA scientists, including Scott Luthcke, who gave a spectacular closing keynote at the ILMF conference in Denver in February—and will give a repeat performance, by popular request, at the January 2019 event. Claudia is writing an article on spaceborne lidar for *LIDAR Magazine*.

As noted in my editorial in this issue, I was privileged to attend HxGN LIVE in Las Vegas in June 2018. During the hectic four days, I was awarded a generous time-slot to talk to Bruce Wald about the HxGN Content Program. Bruce's business expertise provided insightful perspectives and I hope that we can cooperate on an article on this topic, which will be the fourth and final one in this series.

The main purpose of the day, however, had been fulfilled. I had caught up with Ron Roth and seen the ongoing integration of Sigma Space into Hexagon. I had had the honor of more than an hour with Marcos Sirota and now understood some of the brilliance, motivation and sheer scientific and engineering excellence and innovation that undergird the achievements of Sigma Space and have rendered it so very attractive to its new owner. There is no question that the Sigma Space instruments, with their capability for higher altitudes, higher flying speeds and faster data acquisition, will enjoy a growing role, not only in terms of instruments sold to customers within Leica Geosystems' traditional business model but also as resources for valued partners in the content program. Similarly, the company's role in space and defense programs seems bound to expand—the future is as bright as it is intriguing.

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

A large-format, four-band, 12-bit sensor acquired color infrared stereo imagery for high-altitude image collection. Digital imagery collection was completed within seven hours following 20 multispectral imagery data flight lines.
Courtesy of Woolpert

Challenges and Benefits of Infra-water Lidar Technical Support

Ground control, high-resolution lidar and multispectral imagery provide vital information for irrigation and transportation projects in Niger, one of Africa's least developed nations.

The Millennium Challenge Corporation (MCC) is an independent, U.S. foreign-aid agency that invests billions of dollars in partnerships with some of the world's poorest countries to combat global poverty. The agency, created by the U.S. Congress in 2004, targets developing countries that are committed to good governance, economic freedom and citizen investment.

MCC supports these countries by installing an infrastructure critical to growing an economy and building resilience. To do this in these rural regions means ensuring that households and farms have reliable access to water and power, and businesses have dependable roads to connect with customers' expanding markets. This requires high-resolution imagery to understand each country's current conditions and to

BY TIM LEARY


This point cloud was generated using the Pixels-To-Points™ tool and 192 overlapping drone-collected images.
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Woolpert based its flight operations at Diori Hamani International Airport, where the team mobilized its aircraft with the lidar system to prepare for aerial data collection.

Courtesy of Woolpert

create a detailed, efficient plan to make each economy productive.

In 2016, for its work with the Republic of Niger, Africa, MCC contracted with Woolpert for a mapping project that required rapid deployment and the delivery of accurately and efficiently collected data and imagery. This data and imagery would enable the MCC to partner with Niger to provide data for irrigation development planning and road rehabilitation to bolster its agricultural sector, which employs roughly 80 percent of the country's population. Greg Fox, Woolpert geospatial program director, said the project entailed conducting ground survey and acquiring aerial lidar and four-band imagery of 651 square kilometers in the Dosso-Gaya regions along the Niger River and on select road sectors throughout the country, all within a short time frame. "The project had multiple challenges, including international logistics and travel constraints, significant security concerns and tight deadlines," Fox said. "Fortunately, we were able to mobilize within seven days of being awarded the contract, and quickly get en route to helping MCC improve the agricultural future of the region, which would eventually benefit almost four million people."

Deploying to Niger, Adapting to Location

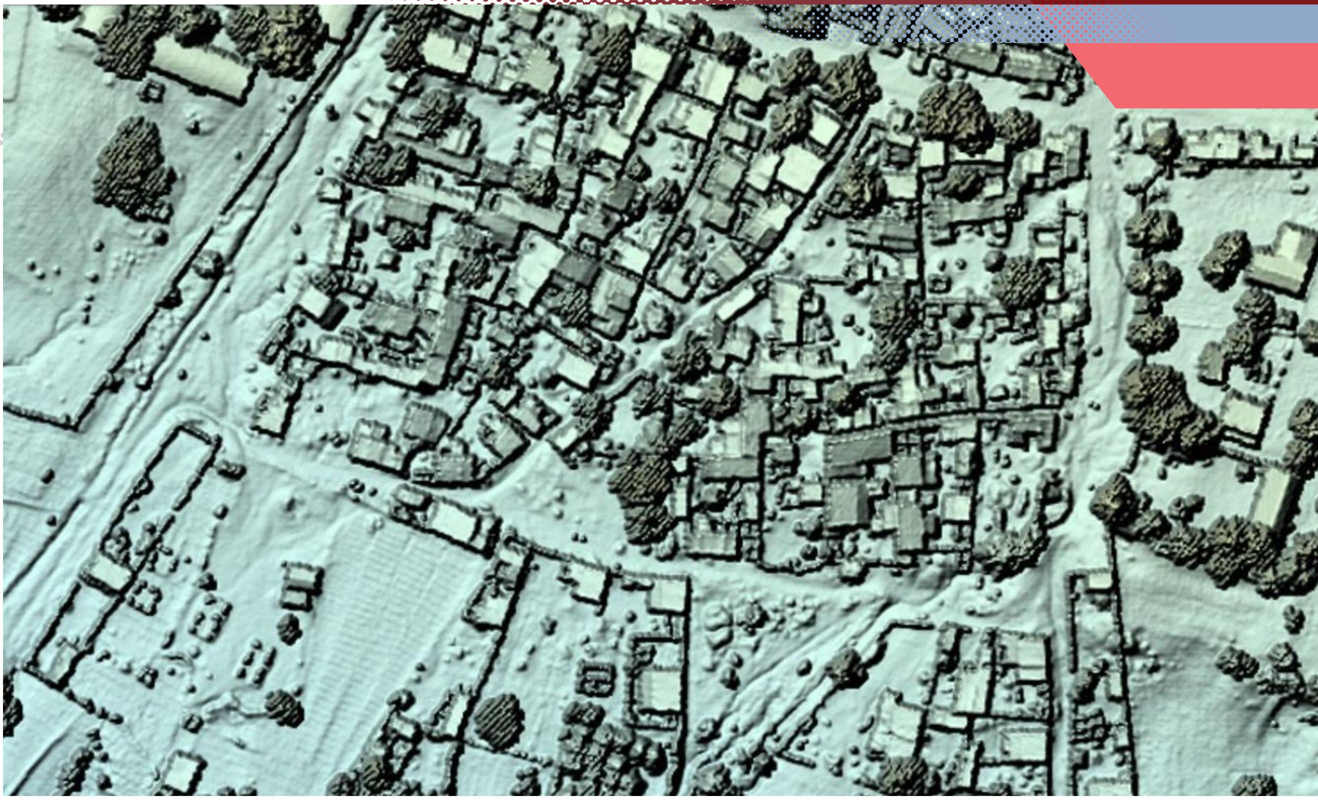
For the Niger project, the Woolpert team furnished the facilities, labor, materials, equipment and aircraft, and handled all landing permits for the transit. Two pilots, including one who was a certified mechanic, also made the seven-day trip.

An advance site survey group was sent to identify adequate accommodations and ground logistics. Once in Niger, the deployed team met with local MCC representatives and other government officials to start the effort. Woolpert engaged with an indigenous company to support ground control surveys.

"Not everything went smoothly," Fox said. "Red tape often resulted in delays accessing the survey area and even our own aircraft."

Each morning, a GPS base station was set up at designated locations in the survey area to support the ground control and aerial survey missions for the day. GPS base station data was collected once per second all day. The ground control survey team had to establish coordinates to support imagery acquisition. The team installed and GPS-surveyed photo control targets and lidar control points throughout the project area. In a few locations, the planned sites had to be repositioned.

"We used open-source imagery for selecting our proposed ground control locations," Fox said. "For the most part, our preselected locations worked out well; however, we did come across a few locations with access issues or locations that posed a safety concern, for which alternatives had to be used."



The project entailed conducting ground survey and acquiring aerial lidar and four-band imagery of 651 square kilometers in the Dosso-Gaya regions along the Niger River and on select road sectors throughout the Republic of Niger.
Courtesy of Woolpert

Ground crews split into two teams, working from one end of the linear study area to the other, to cover more ground and to place all targets before the aerial imagery acquisition began.

Clear skies for aerial acquisition

Flight operations were based in Diori Hamani International Airport, near the Niger capital city of Niamey, where the team mobilized its aircraft with the lidar system to prepare for aerial data collection. The scope of work required highly accurate lidar with nominal point spacing of no greater than 0.5 meters to produce classified point clouds, bare-earth digital elevation models (DEMs), breaklines, contours and model key point digital terrain models.

Cross-shaped targets were painted on pavement for the ground control survey if points fell on paved roadways.
Courtesy of Woolpert

Each morning, a GPS base station was set up at designated locations in the survey area to support the ground control and aerial survey missions for the day. GPS base station data was collected once per second all day.
Courtesy of Woolpert

Fox said the weather was perfect for data collection. “The day the team arrived, a dust storm came through followed by rain, which removed all the remaining dust from the air,” he said. “We were really lucky.”

Operations began on a Monday and were completed by Thursday after seven flight missions, five lidar and two imagery acquisitions. Once the lidar collections were completed, the team quickly uninstalled the lidar sensor from the plane on the runway and began installing the camera system—a large-format, four-band, 12-bit sensor that acquired color infrared stereo imagery for high-altitude image collection.

When the camera system was installed, the team immediately set out for the aerial imagery acquisition at 15-cm pixel resolution. The digital imagery collection was completed within two days.

Processing the Product, Value of Information

Upon completion of the aerial survey mission, the team immediately processed the aerial lidar data, along with the GPS and inertial measurement unit (IMU) data, to produce a raw point cloud for coverage and quality validation.

Back in the U.S., the point cloud was calibrated and classified into ground and non-ground points to eliminate lidar returns for buildings and vegetation from the bare-earth surface model. All non-ground points then were classified as buildings and vegetation. Team members produced the following lidar products: a bare-earth DEM, a classified point cloud, breaklines generated along all defined water bodies and along defined road edges where required to support DEM generation, contours, and a model key point digital terrain model with edge-joined tiles, made seamless with the project area. The multispectral imagery was processed into a seamless RGBN-band mosaic. The software automatically removed unwanted images. In its final form, the mosaic was cut into edge-matched delivery tiles, with special care taken to identify distortions around bridges, overpasses, water towers and radio towers. All lidar and DEM products were delivered within three weeks.

Fox said the geospatial data produced for this project is sufficient for numerous planning and engineering studies related to MCC's projects in the area. The imagery provides valuable land use and environmental information that can help planners and engineers determine potential environmental impacts. The lidar elevation data can be used to determine cut and fill volumes related to roadway construction, as well as for drainage and even floodplain modeling.

"Data of this quality, resolution, accuracy and timeliness can only be provided from aerial platforms and skilled surveying and mapping professionals," Fox said. "And being able to work effectively within the environment is another skillset necessary to make these projects possible."

Lessons Learned, Moving Forward

Fox said conducting international lidar projects requires adjustment due to local and host nation requirements and protocols. He noted a few general recommendations to make these projects progress smoothly.

- Allow sufficient time to plan the trip details before arriving in the country. Pre-planning can help determine a local agent who will look out for your interests and not take advantage of your team.
- Determine the best solution for transporting equipment. Fox said the camera's on-board computer and components were checked as luggage to minimize weight on the aircraft during transit.
- Confirm verbal permission to fly in the country before securing paperwork. Local holidays and/or the whims of local officials may stymie plans. "We were able to secure verbal permissions to conduct our aerial survey mission, but we never received the official letter granting our flight permit until all data collections were complete," Fox said.
- Be courteous to officials. The team made a point to visit the governor and the sultan, who handles tribal issues, to inform them about their presence in the country and what the mapping project would entail.

> "Developing countries are especially interested in taking the next step to become economically self-sufficient and provide security and a future for their people."

Despite the inherent challenges of the project, Fox said the team completed the ground and aerial survey project ahead of schedule and presented accurate, valuable data to MCC to advance its irrigation development planning and road rehabilitation project.

The groundbreaking Niger Sustainable Water and Agricultural Compact, which was signed in 2016 and came into force on 26 January 2018, was the first agreement MCC signed with the country of Niger, which is mostly covered by desert. Establishing and maintaining access to water and transportation helps a country begin to help lift itself from years of severe food insecurity.

Fox noted that, due to the expense involved in mobilizing aircraft, sensors and personnel to conduct aerial surveys in parts of Africa, including Niger, these resources should be leveraged to map the largest possible area for multiple applications. He said this project was the impetus for Woolpert to campaign to work with host nations, MCC and other multilateral aid organizations to think about regional- and national-scale mapping programs. Fox said he was pleased to be a part of this project and the work of the MCC.

"Developing countries are especially interested in taking the next step to become economically self-sufficient and provide security and a future for their people," Fox said. "We are proud to be able to provide this necessary, high-quality mapping that can make a difference in the lives of people whether they're in our backyard or around the world. Participating in a project to help build a foundation for economic growth and food security for an entire nation is especially gratifying."

Tim Leary is a Geospatial Program Director in Woolpert's National Security market, bringing hands-on geospatial experience and his passion for innovation to clients in the military, the intelligence community, government and the private sector. He is a member of the American Society for Photogrammetry and Remote Sensing (ASPRS) and the U.S. Geospatial Intelligence Foundation (USGIF).

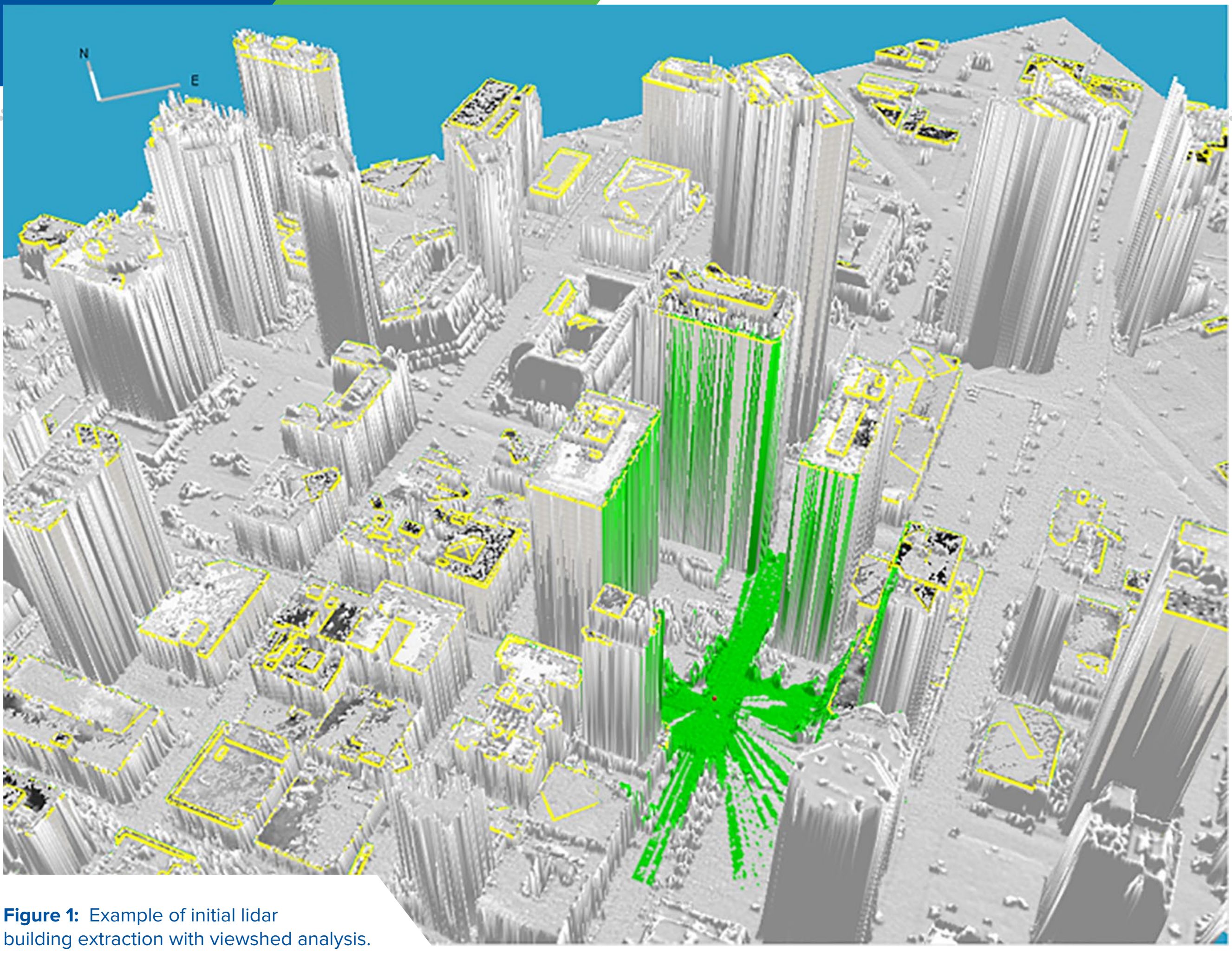


Figure 1: Example of initial lidar building extraction with viewshed analysis.

What Do Geospatial, Northeastern University and Silicon Valley Have in Common? *LIDAR*

A Look at Lidar Education at Northeastern

BY PROF. CORDULA A. **ROBINSON**

Northeastern University (NU) is a top-tier, globally focused, private research university that stresses experiential and lifelong learning. Founded in 1898, it is headquartered in Boston, Massachusetts. NU's global network and reach include advanced degrees and custom corporate engagements at physical campuses in Toronto, Ontario; Charlotte, North Carolina; Seattle, Washington; and now Silicon Valley and San Francisco, California. The California campuses utilize an employer-embedded approach and emphasize an education in science, technology, engineering, and mathematics. The Silicon Valley campus[1] is situated in

1 More information is available at http://northeastern.edu/siliconvalley/.

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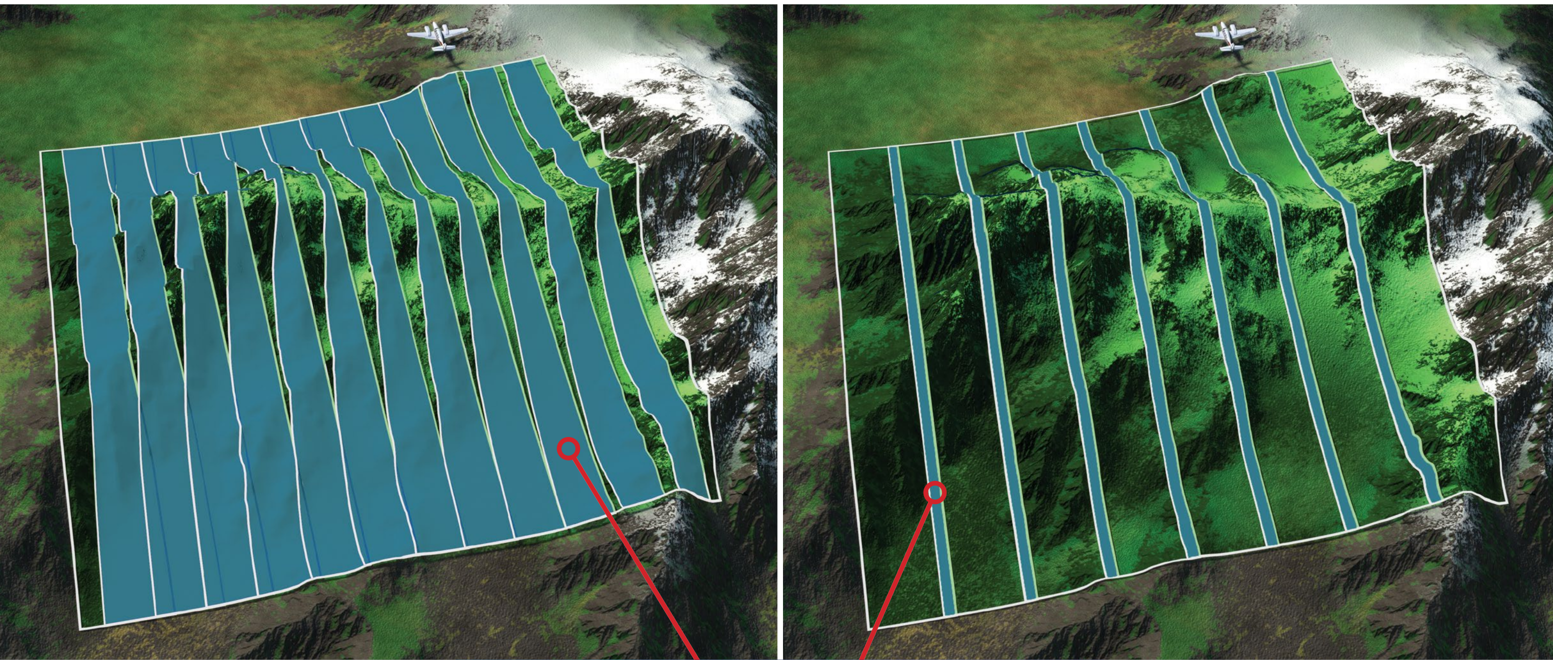

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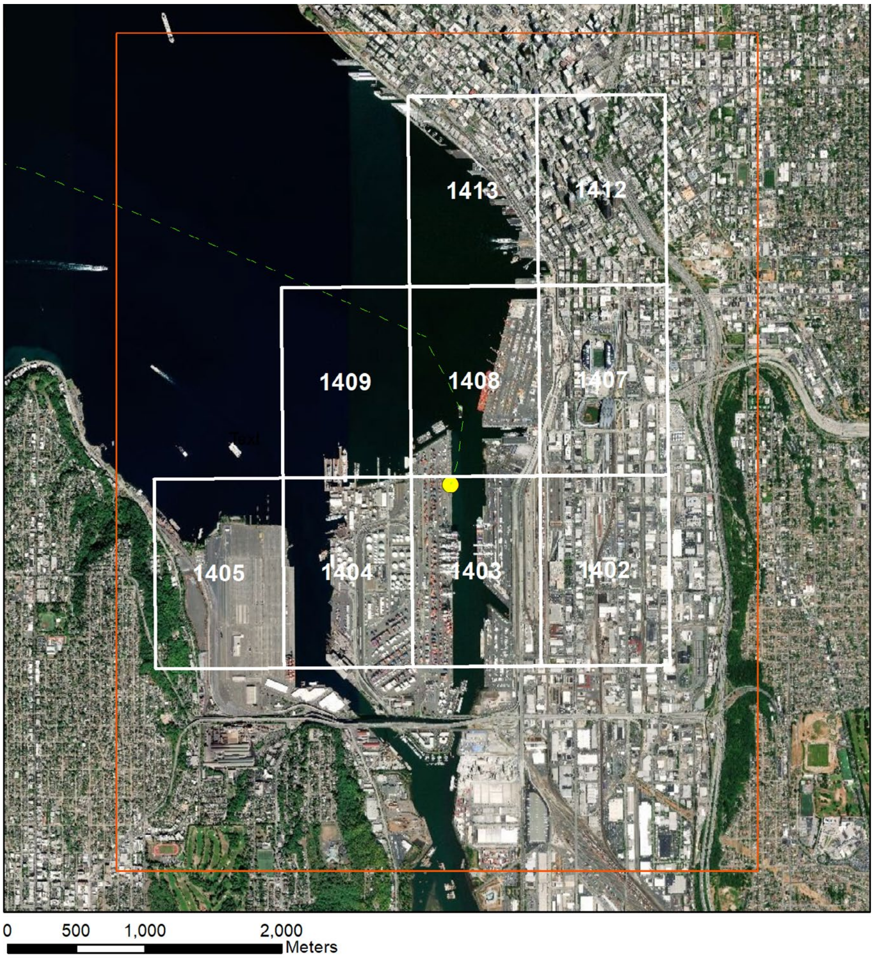


Figure 2: The extent of the lidar processing is defined by the nine tiles displayed within the Area of Responsibility (red outline). LAS files were merged using LAStools, and projected to UTM 10N WGS 84 then classified into ground, buildings and vegetation. The classified LAS file was imported into a Terrain Product, along with an extent boundary, and a simplified water polygon representing Elliot Bay for hydroflattening. Base data source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

San José, the "high-tech capital of the world", as the first education hub to be hosted by a widely respected industry and research leader, Integrated Device Technology (IDT). This pioneering, one-of-a-kind partnership allows students direct access to exclusive real-world learning opportunities, in a globally recognized center of innovation, entrepreneurship, and growth. The San Francisco campus is co-located directly with WeWork, a co-working space for global companies to grow and innovate.

Northeastern's geospatial programs

Northeastern's geospatial programs[2], part of the technology-degree suite, enable students to acquire practical skills and theoretical essentials to lead with geographical xyzt data in the public and private sectors. Particular strengths are in remote sensing and machine learning, including lidar. The program is offered entirely online, ideal for the professional worker needing a flexible schedule. Most classes are about equally weighted between practice and theory. Assignments are conducted between our virtual lab and a student's PC. The high practice content enables student learning to be entwined with the environment in which they live and work. We find the immediate applications to be highly experiential, bridging the world of scholarship and practice. Students can authentically integrate real-world scenarios and examine them through a sometimes outside-the-box and scholarly lens in their workplace, then reflect on the way needs may be addressed with new knowledge they have acquired. We *focus* on cultivating a dynamic online learning "community" as well as student autonomy. Faculty facilitate and guide a student's journey to discoveries, while providing a supportive environment including clear expectations and timelines. Autonomy helps students improve their ability to identify what they need to know, how to set goals, how to seek help, and how to be effective. To quote William Butler Yeats, "Education is not the filling of a pail, but the lighting of a fire"—this is our hope.

When I arrived at Northeastern in 2007, the GIS and remote sensing profession was less mature. GIS dominated in environmental and municipality applications, whereas skills in remote sensing were by and large exclusively available in Ph.D. programs. Thus we commenced an initiative to popularize

2 These are part of a Master of Professional Studies in Geospatial Services program: see https://cps.northeastern.edu/academics/program/master-professional-studies-geospatial-services-online.

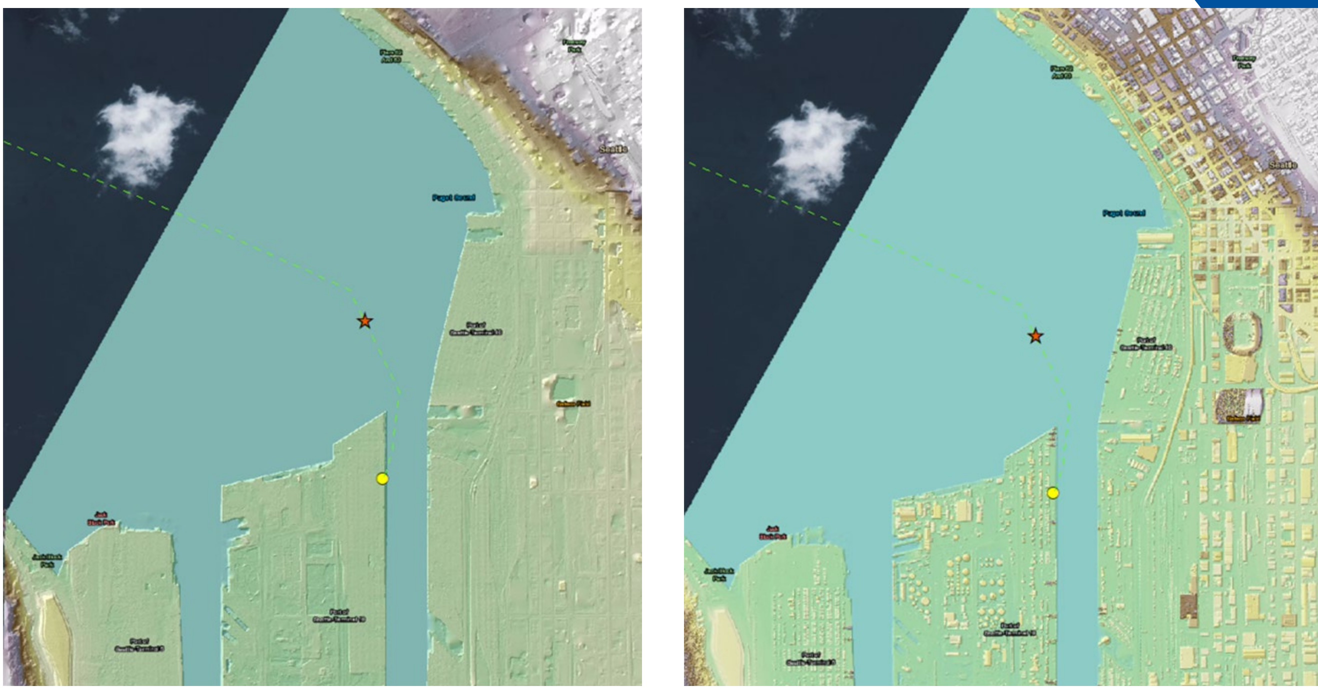


Figure 3: Bare earth DEM with 40% transparency on top of bare earth hillshade (left); first returns DEM with 40% transparency on top of first returns hillshade (right).

the remote sensing skillset. We created a new remote sensing certificate and, soon after, a master's concentration. By 2013, we applied for USGIF Accreditation and subsequently an NGA-USGS Academic Center of Geospatial Excellence designation. These national organizations have helped to steer professionalization of the field and draw from a large body of knowledge and competency models. In-depth curriculum mapping afforded success in both pursuits. The master's degree draws from four hard-skills competencies identified in the USGIF Essential Body of Knowledge[3]. They are:

1. GIS and Analysis Tools: the proper execution of various elements and approaches of GIS and analysis to capture, store, manage, and visualize spatial (location) data;
2. Remote Sensing and Image Analysis: the synthesis of technical, geographic, and intelligence and collateral materials from satellites, airborne platforms, UAVs, terrestrially-based sensors, etc.;
3. Geospatial Data Management: the management, retrieval, and dissemination of data to facilitate integration, analysis, and synthesis of geospatial information; and
4. Data Visualization: to generate products using cartographic and visualization principles for decision-makers.

Cross-functional knowledge areas transcend specific core competencies and include soft skills, described using three competencies:

5. Synthesis: the ability to identify, locate and obtain essential information efficiently and effectively; to decompose problems into parts to facilitate a search for a solution; to draw conclusions, recognize patterns or trends, and determine the consequences of an action;
6. Reporting: to express ideas, information, and facts clearly; to tailor verbal, written, and other forms of communication to intended purpose and audience; to write concisely and explain complex ideas plainly; to solicit constructive feedback from peers and synthesize recommendations for improvement; and
7. Collaboration: for example, to develop and leverage professional networks to facilitate cooperative partnerships that help attain goals.

3 The current version can be accessed at https://usgif.org/system/uploads/3858/original/EBK.pdf. The document is under revision.

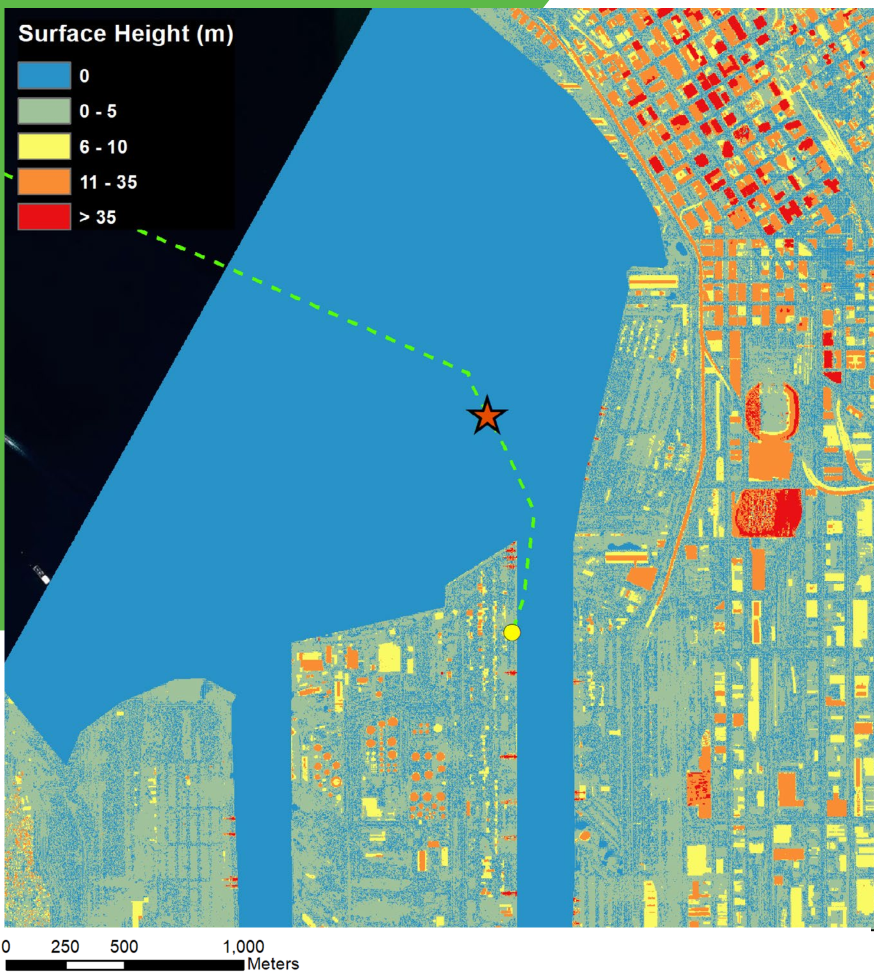


Figure 4: Normalized DSM (NDSM) showing absolute heights displayed with percent clip stretch (min 0.5, max 5), with building polygons, and approach of high-interest marine vessel (HIMV) overlain. Real-time marine traffic data are used for practice, acquired from marinecadastre.gov/data/.

These competencies build on those of other established governing bodies, including The Geospatial Technology Competency Model (US Department of Labor); the Geospatial-Intelligence Professional Certification blueprint (NGA); the Future U.S. Workforce for Geospatial Intelligence (National Research Council); and the Geographic Information Science and Technology Body of Knowledge (UCGIS). They reflect a student's capacity to integrate technical proficiency, creativity, cognitive science, empathy, and contextual cognizance, all necessary for geospatial success. The soft skills emphasize a trajectory to cultivate talent and create bridges. In the hard-skill arena, we "teach to the problem and not to the tools." While we encourage students to equip their geospatial workbench, we also emphasize utility and relevance. Assignments are sequenced and structured to guide students through the process of creating high-quality geospatial products that connect to a broader role of managing, questioning, analyzing, and visualizing such data. Such examples for lidar are provided in this paper.

Geospatial faculty are instrumental in student learning and the program's success. They constitute a rich network of academic and industry professionals who offer their expertise toward program excellence. They include scholars; federal and state employees; and image scientists. Their unique expertise facilitates a rigorous professionally-informed curriculum, while retaining academic depth.

Classes with lidar content

The geospatial program offers four classes with lidar-specific content. A foundational course called "Introduction to Machine Learning for the Geospatial Professional" explores a range of essential routines for digital image processing and big-data development, including enhancement, machine learning, information extraction, data reduction and analysis. Included are a variety of data types from high to low spatial and spectral resolution, SAR, and lidar. We evaluate machine learning approaches (object-based image classification, decision trees, neural networks) and spectral pattern techniques for image classifications. We appraise data integration techniques for combining multi-source and 3D datasets and use quality control and assurance techniques to assign a confidence level indicating reliability of results.

A second offering is our radar and lidar course. As the name indicates, half of the course is dedicated to lidar, covering the underlying principles of measurement techniques and the

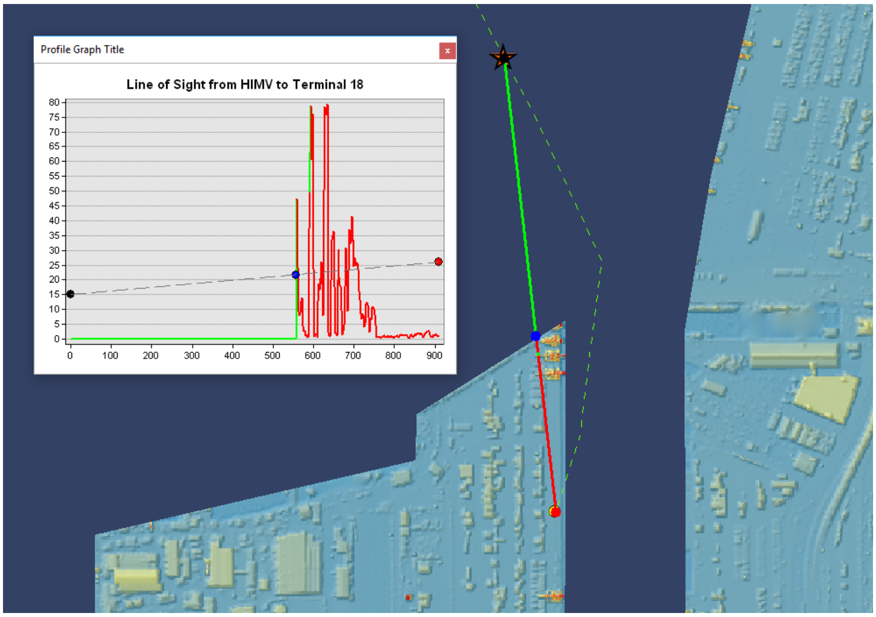


Figure 5: A potential line of sight for an approaching HIMV to the port terminal. It illustrates how tall cargo cranes obstruct the visibility of the terminal's berthing point.

interaction of lidar signals with natural surfaces and the atmosphere. Students are introduced to different lidar airborne and satellite systems, as well as terrestrial systems, principally for urban applications. Students learn how to acquire, manage, retrieve, create, and disseminate data to facilitate its analysis and synthesis. They analyze derivative products, work through application-based exercises, troubleshoot and resolve data-specific problems, then create a variety of spatial features such as buildings, trees, water bodies, land classes and surface layers, perhaps combined with a viewshed analysis (e.g., **Figure 1**). Students work collaboratively via discussion boards to achieve goals through sharing and integrating ideas.

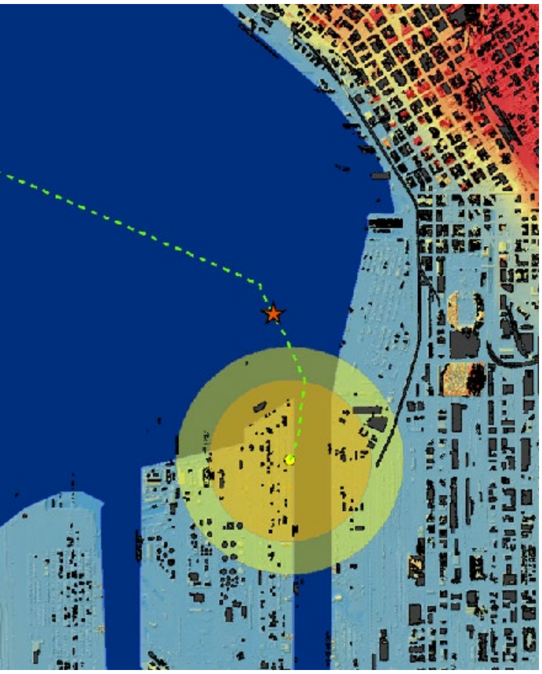
A third and popular class is "Automated Feature Extraction for the Geospatial Professional", which introduces machine learning and automated feature extraction approaches including supervised and unsupervised classification, hierarchical learning, post-processing, clean-up, automation, modeling, and publication. Similar to the radar and lidar course, half is dedicated exclusively to lidar. A focus is how to solve real-world problems and disseminating easily interpretable data to decision-makers. Students are additionally required to troubleshoot and resolve data-specific problems, then use quality control and assurance techniques to conduct accuracy assessments to validate results. A theme throughout our courses is being software agnostic, encouraging instead generic understanding of software capability, and technological fluency. Types of software we introduce include LAStools, FUSION, QGIS, Google Earth Engine, ENVI LiDAR, and Esri. We focus on free, open-source data and any combination of automated feature extraction tools to address a geospatial problem and complete concept-based workflows.

A last complementary course in our lidar suite is "Photogrammetry and GPS". Photogrammetry as a scalable 3D tool is introduced, with a focus on image rectification, ground control and aerotriangulation, digital elevation models, and topographic mapping with discussion around the fundamentals of geodesy.

I taught the automated feature extraction class in spring 2018. I requested a summative assignment that required students to combine workflows for a seaport vulnerability assessment. The workflow is driven by multiple types of open-source data. Students fuse these data into foundational geospatial products intended to help port managers address security concerns for a fictional scenario. The assignment includes data acquisition, processing methods, analysis, real-time data overlays and visualization. Students are asked to process lidar, ortho images and other geospatial data, then perform automated feature extraction, and finally create 2D and 3D analysis products.

Figures included in this paper are example results from this guided assignment completed by graduate student Åsa Bergman. In the first step, students are asked to define the area of port interest (the current situation) and the area of responsibility (AOR; **Figure 2**).The work then proceeds using lidar point-cloud processing and terrain product creation. The lidar dataset used comes from the Puget Sound LIDAR Consortium. Unclassified LAS files, with a nominal point spacing of approximately 1 meter and collected during the leaf-off season, are downloaded along with associated metadata.

In the next step, DSMs are created from first returns and DEMs from bare



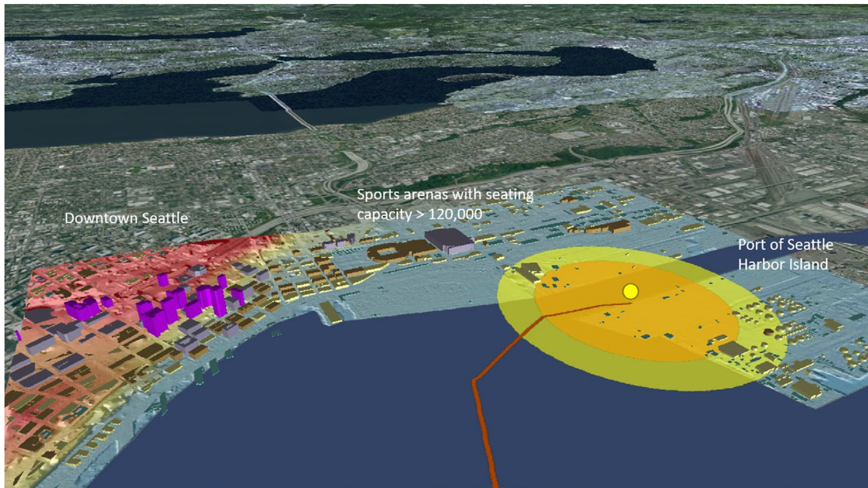


Figure 6: Simulated impacts of an explosion from the high interest marine vessel were modelled using buffers of 500 m and 700 m radius around terminal berthing point: (left) map view; (right) simulation using Esri ArcGlobe.

earth / classified ground (**Figure 3**) enabling the creation of a normalized DSM (NDSM) using the difference between DSM and DEM (**Figure 4**). The NDSM shows absolute feature height. With the data preparation phase complete, integrative techniques are applied for analysis and sensemaking (**Figure 5**).

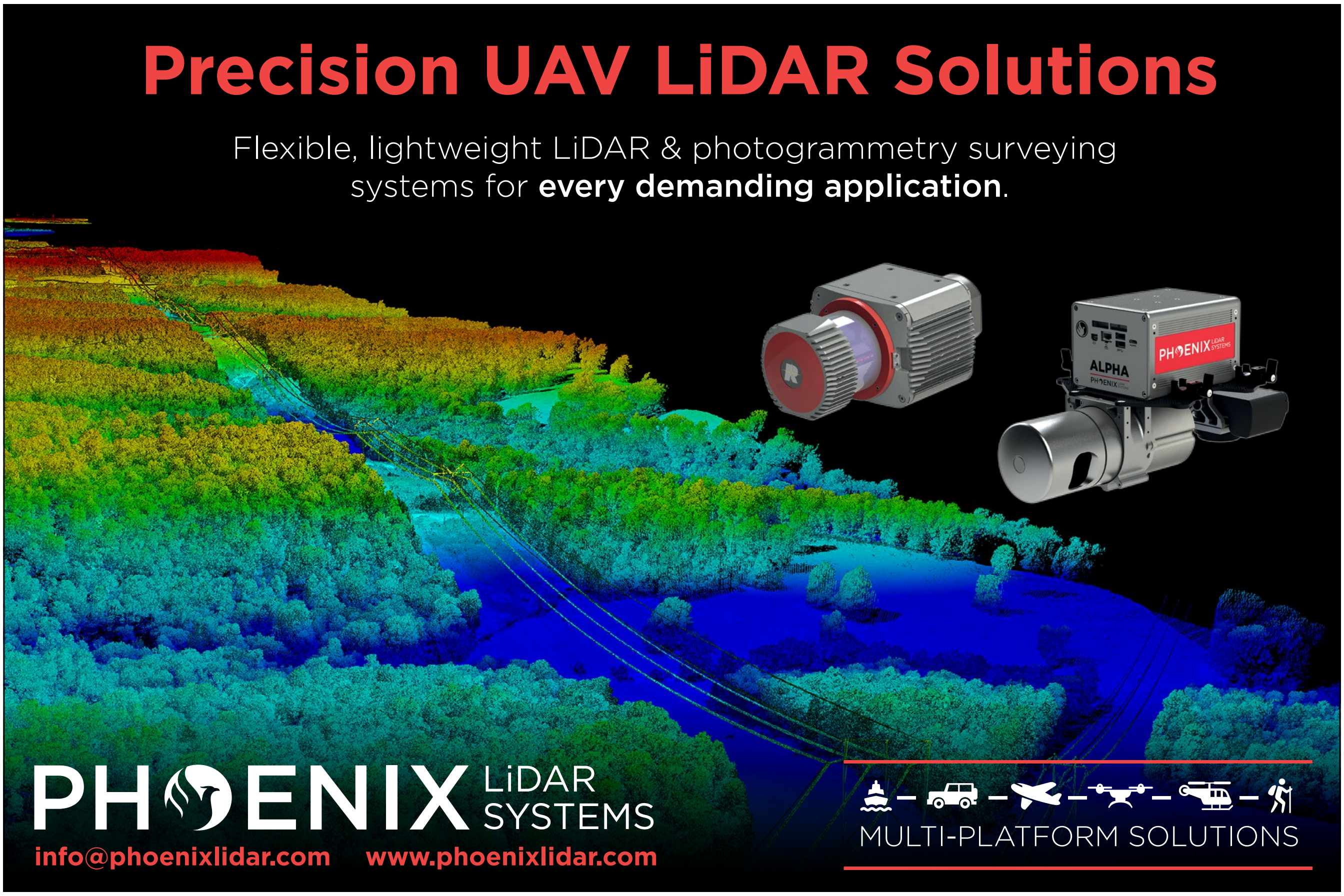
In the next step, simulated impacts of an explosion from the HIMV were modelled using buffers of 500 m and 700 m radius around a terminal berthing point (**Figure 6**). This shows that an explosion at the plotted location would damage buildings, cranes, storage tanks and containers in the port. Toxic air resulting from an explosion could spread across a larger area, depending on weather conditions. Extracted buildings are shown in black.

To date, students have also completed several other lidar-centric projects. For instance, capstone student Colin Johnson focused on 3D volumetric change detection utilizing lidar point clouds. We continue this work, including object-based image analysis, automated feature extraction, and multi-source inputs, advancing toward a neural network, thus facilitating deep learning and detection outputs. More information can be found at https://prezi.com/view/YNVXqZRMz8hDZ6uBAMXD/. Another project includes applications of freely available lidar for Connecticut to extract man-made objects from a primarily forested area and support existing PhoDAR data-collection strategies. Further discussion can be found at https://arcg.is/19emSS.

Endnote

Applications of lidar are ubiquitous and metadisciplinary, driving our curriculum approaches. At Northeastern, we strive to meet workplace needs using an experiential curriculum that bridges introductory to advanced concepts and provides end-to-end education. The goal is to prepare students proactively and thoughtfully for evolving technology and associated challenges. We adopt a generic, thus multidisciplinary approach to problem-solving by combining computer science and analytical skills with functional expertise, creativity, and leadership.

Cordula Robinson joined Northeastern University in 2007 and is a Full Teaching Professor in the College of Professional Studies. She obtained her BSc from Durham University in geology and PhD from University College London in physics and astronomy, then worked as a postdoc at the Harvard-Smithsonian Center for Astrophysics and had an Asteroid, "2942 Cordie", named after her. She continued as a junior scientist at Deutsches Zentrum für Luft- und Raumfahrt (DLR), working on the 2006 mission to Mars. At the end of 2006, she took up a position as a research associate professor at the Center for Remote Sensing at Boston University. She has published widely on a variety of topics in geography, geology and astronomy and has extensive experience in the use of lidar and SAR.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MASTERING LIDAR SENSOR TECHNOLOGY

Realizing the Potential of UAV Photogrammetry and UAV LIDAR Mapping

Flight planning and direct georeferencing make the difference

In his book, *Digital Photogrammetry*, Prof. Toni Schenk writes that "Photogrammetry and cats share a common, most important trait: both have several lives"[1]. This truly describes the technology progression in the photogrammetry industry, which has very rapidly transitioned from analog, semi-analytical, analytical, digital, and soft-copy, to UAV-based photogrammetry for mapping small areas at a low cost. All that is required is a drone that can carry a camera and that images be captured with high overlap/sidelap to cover the area. Processing is handled by readily available commercial photogrammetry software. Accuracy can be improved using better lenses, flying at altitudes that keep image scale consistent between images, and utilizing more and/or less overlap/sidelap. Structure from Motion (SfM) has also emerged as a simplified version of photogrammetry that can create a relative 3D model quickly. Despite the success of low-cost UAV photogrammetry systems, this technology has its challenges, which can be categorized as either *operational* or *principle*. We will discuss these challenges and the solutions offered by Geodetics' Mobile Mapping System (Geo-MMS) family of products.

Operational challenges of UAV photogrammetry include: the time-consuming survey of ground control

1 Schenk, T., 1999. *Digital Photogrammetry, Volume I: Background, Fundamentals, Automatic Orientation Procedures*, Terra Science, Laurelville, Ohio, 428 pp: p vii.

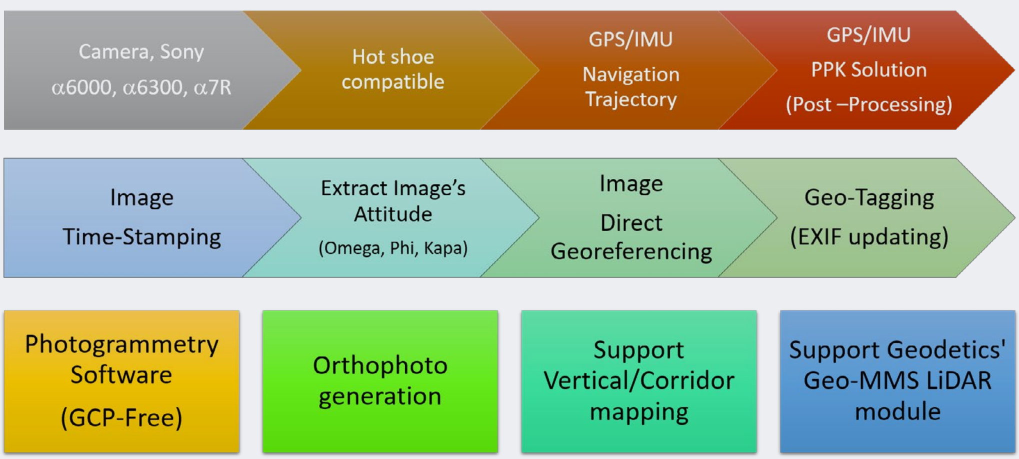

Figure 1: Geo-Photomap workflow.

BY SHAHRAM **MOAFIPOOR**, LYDIA **BOCK**, JEFFREY A. **FAYMAN**

Figure 2: UAV photogrammetry: examples where photogrammetry fails: scale mismatch and missing data under foliage, trees and canopy.

points (GCPs) in and around the area of interest (AOI); considering the number of images captured to cover a particular AOI with the up-to 90% overlap/sidelap required by photogrammetry, locating these GCPs on the captured images can be a time-consuming effort; and processing time can be a day or more.

To overcome these operational challenges, Geodetics' Geo-Photomap product integrates precise GPS/IMU data with an onboard camera, resulting in direct georeferencing of the captured images without the need for GCPs, as well as significantly reduced overlap/sidelap requirements. The key in this process is to tightly control camera-shutter triggering and accurate time-tagging of the captured images for correlation with the inertial solution. The exterior orientation parameters (EOP) of the images, including geographical position and omega, phi and kappa, are interpolated/extrapolated from the GPS/IMU trajectory and added to the EXIF image headers. Once this is complete, the time/geo-tagged images are processed by commercially available photogrammetry packages. This approach also overcomes the problem, encountered in both corridor and vertical structure mapping, of the unavailability of GCPs, as GCPs are not required in this

Figure 3: Point clouds generated by the photogrammetry sensor versus the lidar sensor.

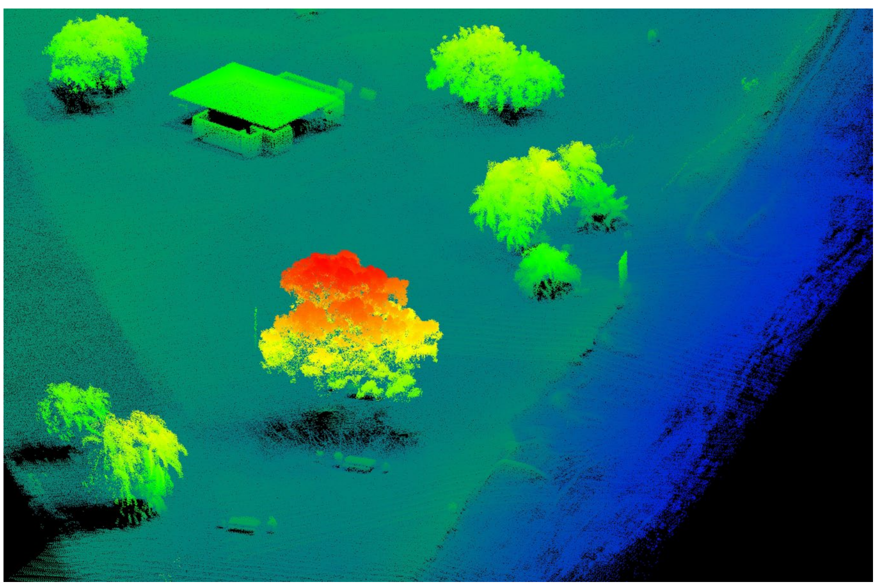

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Figure 4: Colorized point cloud generated by Geodetics' Point&Pixel.

approach. A flowchart of the approach is shown in **Figure 1**.

The principle challenges of UAV photogrammetry include low base-to-height-ratio and short parallaxes, which affect vertical resolution/accuracy. UAV photogrammetry also struggles to perform in areas with low-to-no texture such as foliage, canopy, icefields and flat desert areas. Scale mismatches of more than 20% can cause processing to stop. This problem is due to a shortage in the parallax around high landmarks, such as cliffs or towers in which the relief displacement exceeds the image dimension and predefined scale. **Figure 2** illustrates the principle challenges. For many vertical structures including power poles or trees, point clouds in the vertical component are cut short, and for the areas around foliage, they appear black. Variations in ground altitude can lead to mismatched scale between images, and thus gaps in the scanned area.

To overcome the principle challenges, a lidar sensor can be used as a promising alternative. A lidar aerial mapping payload typically includes a high-performance inertial navigation system coupled with an on-board lidar sensor. Raw lidar data is processed in real-time or with post-mission software to provide accurate, directly georeferenced lidar point clouds. The lidar sensor comes with advantages, such as the ability to map areas with foliage or high canopy, as well as generate DTM/DSM even in areas with no-to-low texture.

To illustrate the advantages of lidar over photogrammetry, **Figure 3** shows the same area mapped with both approaches—photogrammetry above the caption and lidar below. As can be seen, the vertical features that are not captured in the photogrammetry process were accurately captured using lidar (e.g. compare the tree in the center).

Considering the high horizontal resolution provided by photogrammetry and the high vertical resolution provided by lidar, it makes sense to try to merge these two sensors. A combination of point (lidar) and pixel (camera) provides the best of image-based photogrammetry and lidar mapping. The advantages of this integration are: enhanced visualization; lidar point-cloud colorization,

Classic UAV Photogrammetry*			Geo-Photomap Photogrammetry*			Point&Pixel (Colorized LiDAR)		
• Number of images: 1100 • Processing time: 35 Hr • Overlap/Sidelap: 85%/90%			• Number of images: 200 • Processing time: 3 Hr • Overlap/Sidelap: 85%/40%			• AGL: 55m • FOV: 90° • Orthomosaic generated from the Geo-Photomap		
Average RMS on more than 20 check point[m]								
East	North	Up	East	North	Up	East	North	Up
-0.02	-0.06	-0.08	0.01	-0.06	-0.07	-0.04	0.02	0.04

*Sony A6000 camera (focal length: 16mm), AGL: 55m

Figure 5: Geo-Photomap performance versus classical UAV photogrammetry.

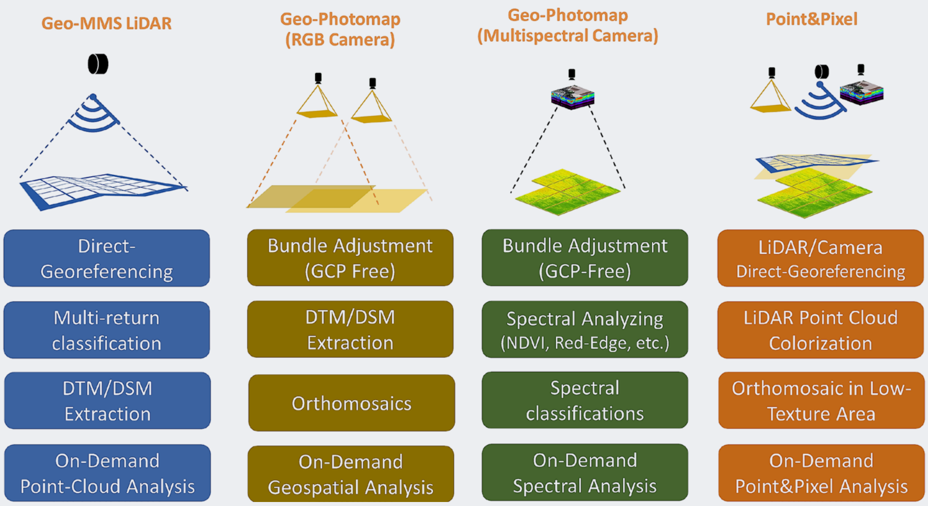

Figure 6: Geo-MMS family of products.

which facilitates lidar point-cloud classification due to the availability of the RGB information; enhanced DTM/DEM extraction after removing the classified objects; orthophoto generation in areas where photogrammetry fails (i.e., glaciers, tree canopy, mine site conveyors, etc.); and enhanced change detection. **Figure 4** shows the integration of point and pixel data, generated by Geodetics' Point&Pixel™ system.

To illustrate the advantages of Point&Pixel integration, **Figure 5** presents a case study comparing the three approaches: classical UAV photogrammetry with high overlap/sidelap using GCPs for geo-referencing; Geo-Photomap GCP-free photogrammetry with geo-tagged images and reduced overlap; and Point&Pixel (colorized lidar point clouds). The RMS values on 20 check points distributed throughout the AOI show similar accuracies for classic UAV photogrammetry and Geo-Photomap. With Geo-Photomap, however, the mission was completed in approximately 25% of the time of the classic approach due to the reduced need for sidelap coverage; furthermore, the data processing time was reduced from days to only 3 hours. This is feasible due to Geo-Photomap's ability to provide image attitude information (omega, phi, kappa) to the photogrammetry processing. The Point&Pixel approach provided accuracy better than 5 cm.

As Schenk rightly predicted, many new technologies are developing around UAV photogrammetry, including remote sensing and multispectral/thermal mapping (e.g. NDVI, EVI and IR indices) used in agriculture/forest management and environmental/disaster preparedness. The majority of existing UAV multispectral systems still collect and process data using the classic photogrammetry approach with GCPs and flights over relatively small areas due to high overlap/sidelap. This approach is not as relevant for disaster preparedness applications, such as wildfire mapping, flood modeling, river survey, ecology and geology, which in many instances preclude the distribution and measurement of GCPs. In these cases, the Geo-Photomap approach can be used to relax the requirements of GCP surveying and flying with large overlap/sidelap to enable mapping of large areas. Geodetics has added a multispectral capability providing spectral classification with all the advantages previously described. **Figure 6** shows the full Geo-MMS suite.

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Lydia Bock is the President and Chief Executive Officer (CEO) of Geodetics. In 2011, Dr. Bock was honored as CEO of one of the 50 fastest woman owned/led companies in North America by the Women President's Organization (WPO)Dr. Bock holds an M.Sc. from The Ohio State University and a Ph.D. from Massachusetts Institute of Technology.

Jeff Fayman serves as Vice President of Business and Product Development at Geodetics. Dr. Fayman holds a B.A. in Business Administration and a M.Sc. in Computer Science, both from San Diego State University. He holds a Ph.D. in Computer Science from the Technion—Israel Institute of Technology.

Graham, *continued from page 48*

useless. The only way you are going to get a handle on true, achievable network accuracy is to go fly a few test projects in your typical operating environment. What I wish vendors would provide (and I have never seen an example of this) is something I would call "intrinsic network accuracy." This INA, if you will, would say what the achievable accuracy would be if the external parameters were perfect. You could then stack typical external factors on this (well, maybe add them in quadrature if they are independent factors) to get an idea of achievable system network accuracy. As I write this, I am looking at the spec sheet of a $150K system. It has a line item specifying "accuracy" as a certain number of millimeters. It does not even say if this is horizontal, vertical, combined? This is useless!

A second issue that bugs me is that precision (noise) is specified in terms of 1 standard deviation (1 "sigma"). Recall what precision means for a laser scanner. If I lock my scanner into a stationary position and repeatedly measure a location in object space that is not changing at all (imagine putting the scanner in a vise and repeatedly measuring the distance to a static wall), then precision is talking about the spread in the range data. For a perfect system, we expect no spread at all. In reality, it will have a spread due to various stochastic errors. If we take a large number of measurements, this spread will have a Gaussian probability distribution (see **Figure 1**).

When we observe a lidar point cloud, all points are visible! This means that points that fall 3 sigma from the mean are quite visible. But worse yet, they manifest as noise points in automated algorithms such as ground classification. In fact, if you use the standard Model Key Points (MKP) algorithm for data thinning, you might realize that you are collecting the outlier noise points!

I think we would all prefer to see the precision of a laser scanner expressed as peak-to-peak or at least 3 sigma. The observable peak-to-peak noise in a laser scanner is at least 6 sigma in width. This is 3 sigma above the true surface and 3 sigma below (so the 99.7% band). This means that if you have a precision specification of 3 cm, you will observe at least 18 cm of peak to peak noise. That is quite a lot! **Figure 2** illustrates a profile of points along a horizontal, smooth concrete pad. These data are from a recent test flight we performed with a calibrated lidar system that employs a Velodyne VLP-16 laser scanner. I have filtered the data to a single return so that flight-line mismatch is not distorting the analysis. Using a planar surface analysis tool in our LP360 point cloud software, I measured the standard deviation as 6.9 cm and the *range* (peak to peak excursions) as 31.7 cm. I think you can appreciate from examining **Figure 2** (the vertical units are meters) that the peak to peak excursions will be more impactful on classification than will the 1 sigma specification.

So what is the bottom line to all of this rambling? It is simply to be careful when using published specifications alone to evaluate a lidar system. No one is trying to be devious; specifications such as 1 standard deviation rather than peak to peak are probably due to historical precedence, not an attempt to obscure.

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

LEWIS GRAHAM

Oh, One More Thing...

For years our company has provided software, consulting services, training and just about everything associated with lidar except the actual hardware. Of course, our staff has a lot of hands-on experience with lidar systems but we've not had the pleasure of owning one. Now, on the drone side of our business, we are selling and supporting lidar units. This has caused me to take another detailed look at specifications and what they truly mean.

While the column this month focuses on drone lidar systems, the observations are applicable to all geospatial laser scanning systems. I am not going to give a list of specifications and what they mean (that would be a substantial, full-length article) but rather will delve into a couple of specifications that may trip you up.

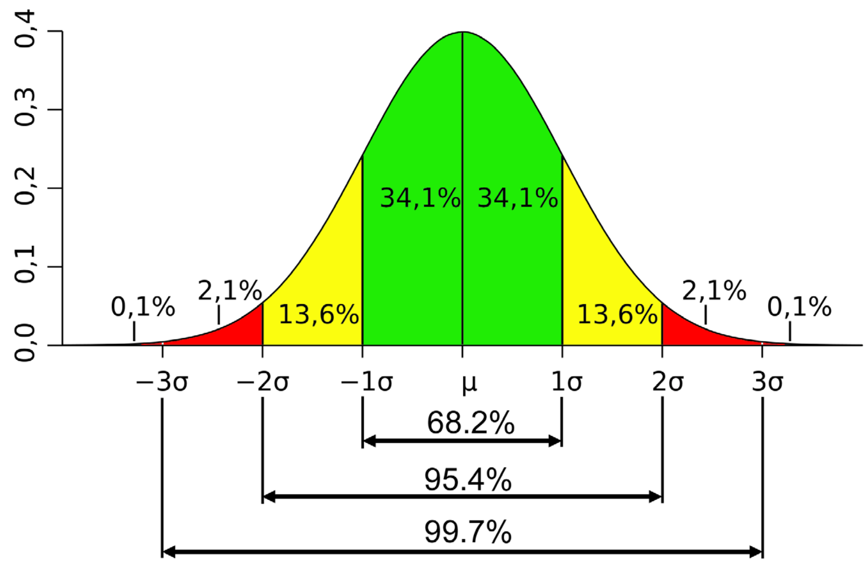

Figure 1: The Normal Distribution

The first one (and my pet peeve) is "accuracy." This specification appears on nearly every integrated system specification sheet, but what does it mean? First of all, we assume that the spec writer really meant "network accuracy" (what is often erroneously called "absolute accuracy"). As has been discussed in previous Random Points, network accuracy is how "close" the data under question are to a reference geodetic network. We usually measure this by comparing our collected data to some collection of "check points." These check points are, in turn, tied to a geodetic network either via traditional surveying or via a GNSS technique such as RTK. We don't have to, but we usually express this accuracy as a root mean square error (RMSE).

If you make a list of all the factors that can affect the network accuracy of a kinematic laser scanner, it gets pretty long. It includes extrinsic (that is, external to the senor system) items such as satellite coverage, atmospheric conditions, flying height,...—the list goes on and on. Then there are myriad intrinsic factors to consider. I maintain that a vendor could parameterize the intrinsic factors but cannot say much at all about the others. To me, this makes the figure of merit they call "accuracy"

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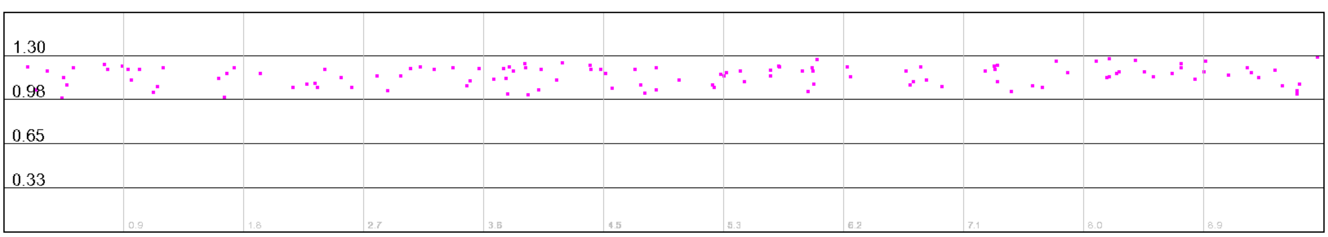

Figure 2: Hard surface range for a low precision lidar

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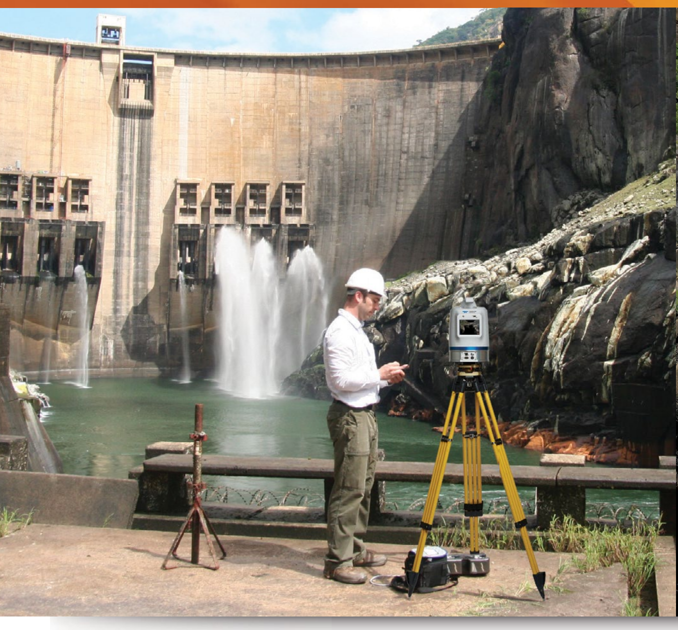

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