LIDAR MAGAZINE

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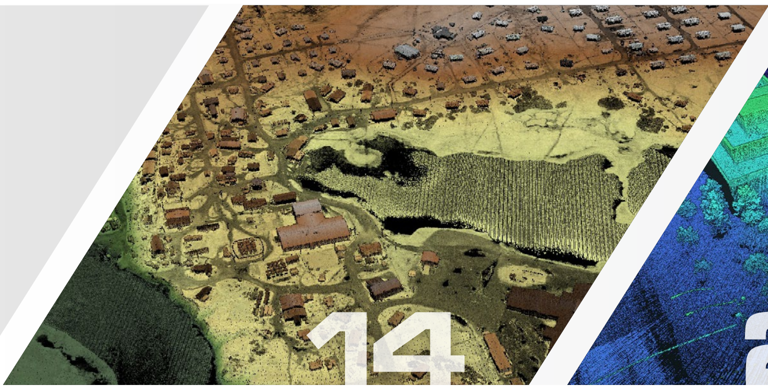
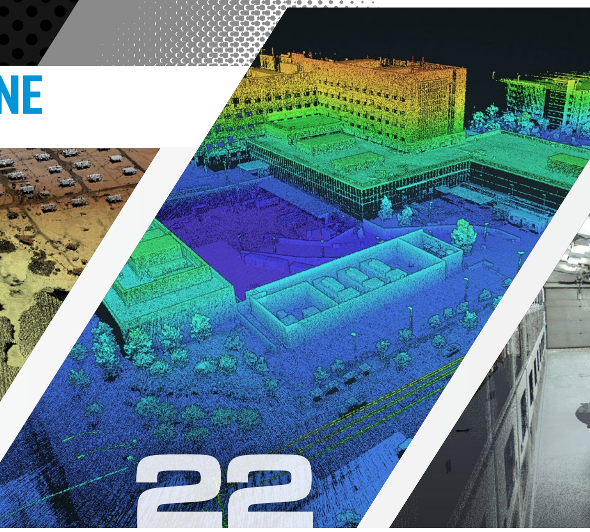
MAPPING ALASKA

LIDAR MAGAZINE





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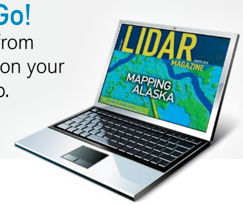

◀ ON THE COVER

Digital elevation model of the village of Newtok, Alaska. The linear feature in red is a runway.

Courtesy of Woolpert

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A Furtherance of Achievements

I wish readers a successful and fulfilling 2018. What better way to start the year than the International LIDAR Mapping Forum (ILMF) in Denver! This conference is epochal, because for the first time it is co-located with the annual conference of ASPRS, resulting in richer, more extensive technical programs, workshops and exhibition than ever before. I am deeply involved in the LIDAR Leaders Awards, the new initiative of Diversified Communications (the company that runs ILMF and several other events in our field) and *LIDAR Magazine*. There were no less than 86 nominations, providing numerous high quality candidates in all three categories—Enterprise, Team and Individual. We've highlighted many of them in the preview you'll find on page 6. See our March publication for an in-depth look at the winners.

This year's technical programs—one for ILMF and one for ASPRS, though most attendees are purchasing registrations that enable them to participate in both—are very enticing. The preconference workshops and events comprise both the range of topics characteristic of ASPRS conferences but also two ILMF events about Riegl products and the LAS format specification. Simultaneously, the ILMF product previews, sequences of quick pitches from suppliers, proceed apace. It is unhelpful here to attempt a precis of the technical program, since readers will have it before they receive this magazine! Suffice it to say that both the ILMF and ASPRS programs provide attractive plenaries, keynotes and parallel sessions. The ILMF sessions typically involve two parallel sessions and the ASPRS ones, four, there are poster sessions too, so participants should never be short of a relevant topic. If I am to enjoy my privilege as editor to highlight a presentation or two, I am delighted that Professor Uwe Sörgel from the University of Stuttgart, who was featured in the December 2017 issue, will be speaking about bathymetry. As you have read, Uwe and I share the same interpretation of current trends: the way of the future is professional selection and use of complementary technologies, including electro-optical imagery, SAR, LIDAR, sonar, thermal, conventional land surveying and others. Secondly, just as I was writing this, ASPRS confirmed their closing keynote, to be given by NASA luminary Scott Luthcke, who will focus on NASA's Earth-observing, space-based LIDARs (SLA-1, SLA-2, ICESat-1, ICESat-2, GEDI): we mainly work in airborne LIDAR, TLS, MMS and automotive, but spaceborne sensors are a less familiar, tantalizing and enthralling aspect of our field.

Each of us has our favorite technologies or project scenarios in the LIDAR world and we all try to discern the trends that will influence the industry or the innovations that will become "game changers". It's

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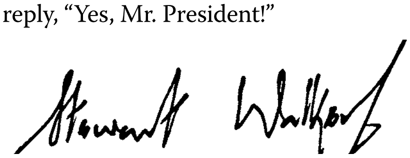
clear, for example, that large projects will continue to be executed from manned aircraft and helicopters, using LIDAR sensors and cameras that offer better and better price/performance. Single-photon and Geiger-mode will strive to become part of the LIDAR "establishment". The excitement surrounding UASs will not abate and the availability of LIDAR sensors for these aircraft and the enormous expertise on the integration side will ensure impressive growth. Around the world, many more jurisdictions will make their LIDAR holdings available free of charge and we can be sure that there will be portals and software to facilitate their use. We are conscious of the huge automotive market, in terms of both autonomous vehicles and advanced driver-assistance systems (ADAS), driving the development of technologies that can be exploited for UAS LIDAR and mobile mapping systems. Less visible, so to speak, are underwater LIDAR and LIDAR from space, but there is plenty of evidence that these application areas will be active in 2018. We will all find something to intrigue, impress or involve us!

Let's go back in time. During the holiday season celebrations in our home, my architect son-in-law gave me his copy of Douglas Preston's 2017 bestseller, *The Lost City of the Monkey God* (Grand Central Publishing, New York, 328 pp; parts had already appeared in *New Yorker* and *National Geographic Magazine*). This transpired to be a compelling account of the discovery and investigation of a "lost city" in Honduras. LIDAR was the hero: after the area was flown at the beginning of May 2012, the results astounded the first viewers—LIDAR had seen through the dense tropical rain forest and found geometric ruins beyond archaeologists' wildest dreams. The book has been written for the general public and is an easy read, summarizing decades of exploration before the days of LIDAR, then grippingly guiding readers through the expedition and its aftermath. Some passages, featuring poisonous snakes, creepy-crawlies and the nasty diseases contracted from them, are not for the squeamish. LIDAR folk, of course, will be not unfamiliar with published accounts of LIDAR discoveries. The LIDAR expert on the Honduras expedition was Dr. Juan Carlos Fernandez Diaz (University of Houston), who had an article seven years ago, "Lifting the canopy veil" in *Imaging Notes*, volume 26, issue 2, pages 31-34, describing LIDAR mapping of the Mayan city of Caracol on the Vaca Plateau of Belize. And I remember Christopher Begley, Associate Professor of Anthropology at Transylvania University, beginning the technical program of the ASPRS 2014 Annual Conference in Louisville, Kentucky, with a fascinating keynote on "Lost cities, lasers, and the vestiges of the colonial discourse of archaeology". Professor Begley made some controversial inputs when the expedition in Preston's book returned from the field. Archaeology, like most fields, has its rivalries and tiffs; irritations, like sand in the oyster, can generate pearls of intellectual progress!

Returning to the 20th century, my library has unearthed further nuggets as the scanning process continues. I found a reprint, curiously on paper of size 8.5 x 22 inches, from *Surveying and Mapping*, vol. 24, issue 1, March 1964, pages 75-82, of a *tour de force* by Walter S. Dix, president of ACSM at the time, "The land surveyor of the future". After masterfully articulating his review, Dix quoted (p82) President John F. Kennedy, enunciating a mellifluous paragraph at the ACSM 1962 convention:

> "Since the beginnings of our Nation, those of your professional calling have contributed in full measure to its opening, growth and development. Today, our horizons have extended beyond the limits of the imagination of our forebears. They who founded our Nation included in their numbers men whose professional efforts were devoted, as are yours, to the description in ever more precise terms of the world about us. Then, as now, this effort has made possible even fuller use of the God-given resources available to us. I know that you, with the inspiration which has characterized the work of your profession, are more than equal to the challenge of the future. Among the great contributions on which all of us can count is your continued and valued support of the educational development of those who will follow you. Your efforts in their behalf will help to assure a furtherance of achievements thus far realized."

As we gather in Denver for the 2018 ILMF/ASPRS, learn new skills in workshops, applaud the winners of the LIDAR Leaders Awards, listen to the presentations, view the exhibition and network with droves of committed, keen professionals, I think we can assuredly reply, "Yes, Mr. President!"



A. Stewart Walker // Managing Editor

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AWARDS PREVIEW

LIDAR LEADER AWARDS

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2018 NOMINEE PREVIEW

In conjunction with the first ever co-location of the American Society of Photogrammetry and Remote Sensing (ASPRS) Annual Conference and the International LIDAR Mapping Forum (ILMF) in Denver, the inaugural "LIDAR Leaders" awards ceremony will be held. The 2018 program addresses three distinct categories:

Outstanding Personal Achievement in LIDAR

Eligible individuals must have made significant impact to their organization, local or national community, involving technical excellence, professional development or innovation within the realm of geospatial LIDAR technology,

Individual Nominations

Carlos Aiken
Professor—Geoscience
University of Texas at Dallas
Academic

Mike Aslaksen
Chief, Remote Sensing Division (NOAA)
NOAA
Government

Matt Bethel
Director of Technology
Merrick & Company
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Tim Blak
Senior Vice President of Technology
Atlantic
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Houssem El Baccari
searcher
cnrs
Asset Owner/Operator/ Facility Manager

Obadyah Foord
Director, Geospatial Services
Rice Associates, Inc.
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Dr. Jörg Hacker
Director
ARA—Airborne Research Australia
Asset Owner/Operator/Facility Manager

David Hall
Founder & CEO
Velodyne LiDAR
Asset Owner/Operator/Facility Manager

Andre Jalobeanu
President
BayesMap Solutions, Inc.
Hardware Manufacturer or Software Developer

Alvan Karlin
Senior GIS Scientist
Southwest Florida Water Management District
Asset Owner/Operator/Facility Manager

Omer Keilaf
Co-founder and CEO
Innoviz Technologies
Hardware Manufacturer or Software Developer

Michael Kiehn
Head of Sensor Development
Ibeo Automotive System
Asset Owner/Operator/Facility Manager

Gregory Lepere
Director
Trimble, Inc.
Hardware Manufacturer or Software Developer

Bharat Lohani
Professor
Indian Institute of Technology Kanpur
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Elise MacPherson
Associate, Senior Project Manager
Dewberry
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Dr. David Maune
Associate Vice President
Dewberry
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Grayson Omans
CEO
Phoenix LiDAR Systems
Hardware Manufacturer or Software Developer

Arttu Soininen
Software Developer
Terrasolid OY
Hardware Manufacturer or Software Developer

Bobby Tuck
President
Tuck Mapping Solutions, Inc.
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Dr. Andreas Ullrich
Chief Technology Officer
RIEGL
Hardware Manufacturer or Software Developer

James Van Rens
Senior Vice President
RIEGL USA
Hardware Manufacturer or Software Developer

Ruisheng Wang
Associate Professor
University of Calgary
Academic

Clay Wygant
LiDAR Operations Manager
Maser Consulting, P.A.
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Bisheng Yang
Professor
Wuhan University
Asset Owner/Operator/Facility Manager

AWARDS PREVIEW

Outstanding Team Achievement in LIDAR

Eligible teams must demonstrate unique achievement in the area of service, project management, product development or other specialty accomplishment within the realm of geospatial LIDAR technology. Open to private and government organizations, teams of 2-99 members.

Team Nominations

AEye/iDAR (Intelligent Detection & Ranging)
Hardware Manufacturer or Software Developer

Cepton Technologies, Inc.
Hardware Manufacturer or Software Developer

Dewberry Geospatial and Technology Services Team
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Engineering Grade LIDAR survey for Corridor mapping in LATAM
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Entwine
Asset Owner/Operator/Facility Manager

Forest Resource Assessment Nepal
Government

GaN Transistors for High Resolution LiDAR
Hardware Manufacturer or Software Developer

GaN Transistors for High Resolution LiDAR
Hardware Manufacturer or Software Developer

Kaarta
Hardware Manufacturer or Software Developer

Laser Scanning Forum
Academic

NOAA Office for Coastal Management—Lidar Team
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

North Carolina Statewide Lidar Collection 2014-2018
Government

Phil LIDAR 2: Nationwide Detailed Resource Assessment
Academic

PHIL-LIDAR-1: Hazard Mapping of the Philippines
Academic

Princeton Lightwave, Inc.
Hardware Manufacturer or Software Developer

Pt. Map Tiga Internasional
Service Provider—EPC, AEC, Surveyor, Consultant, Reseller

Single Photon LiDAR Technology Development Team
Hardware Manufacturer or Software Developer

YellowScan
Hardware Manufacturer or Software Developer

Outstanding Enterprise Achievement in LIDAR

Eligible organizations must demonstrate exceptional achievement as a group of 100 members or more, in the area of service, project management or product development within the realm of geospatial LIDAR technology. Open to private and government organizations.

Enterprise Nominations

ATLAS Development Team/ NASA ICESat 2 Mission
Dr. Thorsten Markus
Hardware Manufacturer or Software Developer

Innoviz Technologies
Liron Eldar
Hardware Manufacturer or Software Developer

NASA/JPL ASO
Tom Painter
Government

Quantum Spatial
Russ Faux
Asset Owner/Operator/Facility Manager

Scripps Institution of Oceanography
Adam Young
Asset Owner/Operator/Facility Manager

Teledyne Optech
Michel Stanier
Hardware Manufacturer or Software Developer

USGS 3D Elevation Program (3DEP) Team
Michael Tischler
Government

Congratulations to all of this year's nominees. The March edition of *LIDAR Magazine* will contain a showcase of the winners.

GEOTECH INSIDER

Patrick Cunningham is the President of Blue Marble Geographics, Hallowell Maine. Cunningham offers nearly two decades of experience in software development, marketing, sales, consulting, project management and corporate management. Originally joining Blue Marble as Director of Business Development in January 2003, Cunningham assisted with the sale of the company and took over the reins in February 2004. We caught up with Patrick to discuss the company's flagship app, Global Mapper, LIDAR and Cloud solutions and the outlook for BMG in 2018, their 25th anniversary!

PATRICK CUNNINGHAM

Blue Marble Geographics

You've recently updated the Global Mapper LIDAR Module optional add-on. For anyone not familiar with this, who is it for and why do they need it?

The LIDAR Module for Global Mapper is a powerful add-on extension for in-depth LIDAR data manipulation, analysis and conversion applied to any 3D point cloud. It has tools for automatic classification of raw unclassified points, automatic feature extraction into 3D objects, terrain module generation, custom feature extraction and a host of manual clean up tools along with a special Path Profile toolset. The Module also now features a new Pixels-to-Points™ tool for converting imagery to point clouds.

What sets this tool apart from other LIDAR data management solutions?

The beauty of the LIDAR Module is that it matches up very well against other LIDAR processing tools in features and functionality, yet for a fraction of the cost. This is not just my opinion, our customers have repeatedly, independently verified this. Most equivalent tools start at an outrageous $5,000 for a single user license whereas the Global Mapper LIDAR Module starts at $499 for the same license. It's simply the cost of another seat of Global Mapper. So if you have a single user license of Global Mapper with the LIDAR Module the cost is only $998. That price combined with the functionality dramatically sets it apart from other solutions.

I'm curious about the Pixels-to-Points tool in the LIDAR Module. Seems you've targeted this at those using UAV data collection. Can you share a bit about this?

Sure. The Pixels-to-Points tool was developed for our customers that fly drones and UAVs; they have been asking us for this type of functionality for a while. Still in beta, the tool is a brand new interface for converting drone collected imagery into 3D point clouds. It provides an interface for organizing the data, reviewing it, creating a raster orthoimage and then converting the pixels to a usable hi-resolution point cloud. Because this feature set is incorporated in our very power LIDAR Module, it makes the work of cleaning up the point cloud and leveraging intelligence from it that much easier. This one stop approach will save customers time and money.

Both LIDAR and UAV technology are exploding in use and seem to go well together. Are there more ways that you support the UAV user and is this a big market for BMG?

We have been very popular among UAV operators for a while now because of the combination of affordability, feature set and ease of learning the software. It's kind of a triple threat. For the single person company that is starting a new venture, they can afford the tool and they can figure out how to use it. For the larger enterprise, the interoperability of Global Mapper just makes sense. Our UAV customers use Global Mapper for everything from flight planning to terrain model generation, contour generation, NDVI and change detection to a host of other GIS workflows. Additionally, our UAV customers like to refer their customers to Global Mapper to use as a data viewer because it is so easy to use. Consequently many of them provide the software with their data delivery or simply point people to us. We even have a Drone Reseller program for these customers so they can work towards getting a commission on those sales.

I'm always amazed at the price of your solutions… it's incredibly affordable. You must have tremendous customer and user retention, is that so?

We do have a very loyal customer base. Many users have been with us for years. We come right out and say it; we go to market as the affordable GIS solution. There is a need for that in the marketplace. Our applications fill the void between open source (free) applications with limited or no support and overpriced, older enterprise solutions that are locked into some verticals. Perhaps the biggest challenge we have is educating our prospective customers, especially those using the antiquated over-priced stuff, that you can do all the GIS you need with inexpensive software. Inexpensive does not mean low quality and it does not mean a lack of tech support or training. We provide all of that.

Can you share Which industry segment or user base do you see adopting LIDAR solutions?

LIDAR is slowly being adopted by all areas of GIS as more and more LIDAR becomes available. At first it was the surveyors, then government, but now it is everyone from global engineering firms, oil and gas majors and municipalities. If you're doing GIS today you will be using LIDAR.

I see there's a free trial download available. What can people do with the trial? Is it limited in functionality?

You can do everything you can with the commercial version, you are just limited by how many times you can output or save things.

You've been offering training throughout the year I see, how has this been received and will it continue? What goes on in a day of training?

Our training program continues to grow. We conducted training from Maine to Perth last year and we plan to do so again. Our resellers are now offering localized training around the world in addition to our direct services. We offer public training, private on-site or interactive web sessions. We're always trying to improve our training, the feedback has been very positive to date but we strive to continue to make it a great solution for our customers that need it. Over the past few years we rolled out a Global Mapper Certification process for our users and resellers so now folks can get professional recognition for their skills with Global Mapper.

Shift focus to the company, how was 2017 for BMG? Any surprises?

2017 was a great year for us. We did see revenues again grow over the past year and our user base expanded as well. You've hit the nail on the head that Drone users are driving some of that, but engineering, oil and gas, alternative energy, gaming companies, and federal, state and local government are other growth areas. I would say the adoption of Global Mapper by the gaming companies has been a pleasant surprise. If you're kid plays it on X-box or similar gaming console, the company that made the game uses Global Mapper to create terrain models and other 3D output. They are all household names literally. We have put a lot of work into our 3D features and it is starting to pay off.

Looking forward, what are you excited about for the company that you can share?

2018 represents a significant milestone for Blue Marble Geographics as it is our 25th anniversary and we are planning some special events to thank our customers who have been with us and made all this possible. Our first announcement is coming soon where we have decided to pay it forward by having each our employees name a charity of their choice that we will donate $100 to in their name. Personally, I am excited about Pixels-to-Points. We are playing with drones now and it is a lot of fun. However, I am also excited about our work on cloud hosted versions of our software and that work will continue this year where you will see us role out new offerings around the cloud.

For those users that should be using LIDAR but aren't yet, why should they consider LIDAR in their org?

In the U.S. where free publicly available LIDAR data is waiting to be used, it's a no-brainer. You can supplement your GIS work relatively easily with LIDAR where you can create high resolution terrain models, accurate contours, precise volumetric measurements, 3D vegetation and buildings all with very little effort with a tool like Global Mapper. Internationally, LIDAR is not quite as accessible but if you can get it, you should look at the products that you can create from the data because it really can augment your GIS both in 2D and 3D.

Finally, would you care to share an industry projection or outlook that you see coming?

I guess I would just say that the point of all of this is that 3D mapping is no longer a thing of the future; it's now. There is still a place for top-down 2D mapping but more and more end-user map consumers will want 3D maps. So we would see GIS heading that way. As we continue to add value to business decision making through new compelling tools we will see the GIS industry grow. As an industry we have innovated quite well over the past decade, both LIDAR and Drones are a big part of that so there are a lot of folks watching what we are doing. If we deliver, that can only be a good thing for industry growth.

Interview by **Glenn Letham**, Managing Editor of GISuser.com

The Future of Aerial Lidar and Emerging Technologies

JEFF LOVIN

Woolpert Senior Vice President and Director of Government Solutions

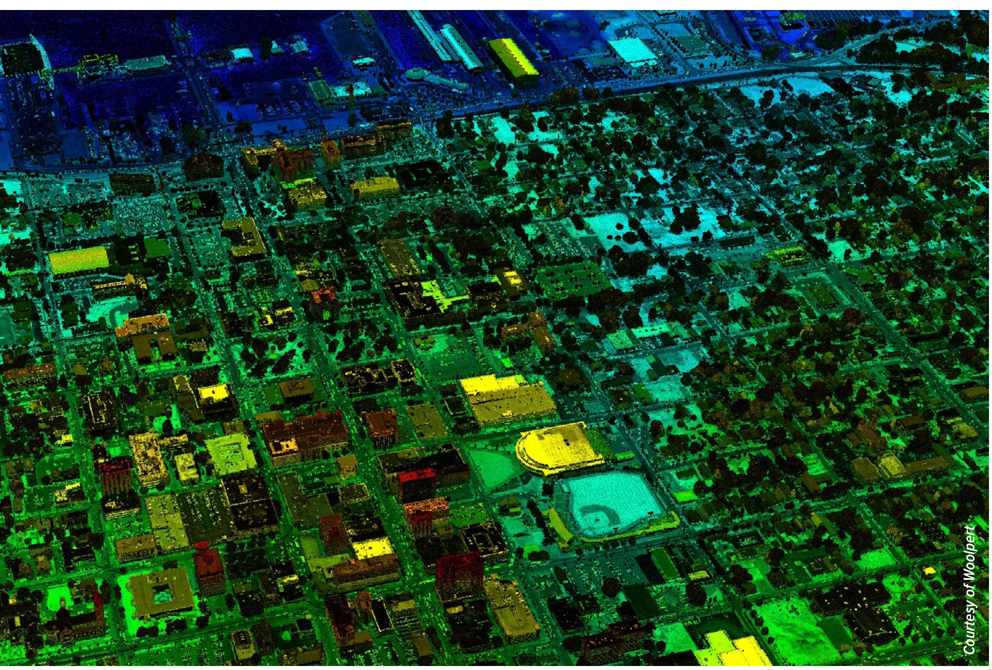
Lidar, which can generate up to 10 million pulses per second or more, creates a dense terrain model of unmatched accuracy when compared to manual photogrammetric collection. As a result, it is the most efficient three-dimensional modeling and surveying method available.

There are multiple lidar sensor technologies available and others in development, with varying data collection factors for multiple data applications.

Linear mode lidar has been the most conventionally used aerial lidar approach for several years. Recently, the advent of single photon and Geiger-mode lidar sensors have brought new methods and applications of lidar collection to light.

These advancing technologies have raised the question—especially for those currently making long-term, large-scale investments in these services—as to whether one aerial lidar methodology will emerge and eclipse the others or whether the industry will support multiple lidar methodologies.

Given the breadth of projects utilizing this technology and the varying applications of the data, I believe not only will a variety of aerial lidar methodologies continue to coexist, but that the data delivered to clients will be more affordable and specific to a growing array of client needs.



This image of Erie County, Pa., was captured by Woolpert via linear mode lidar.

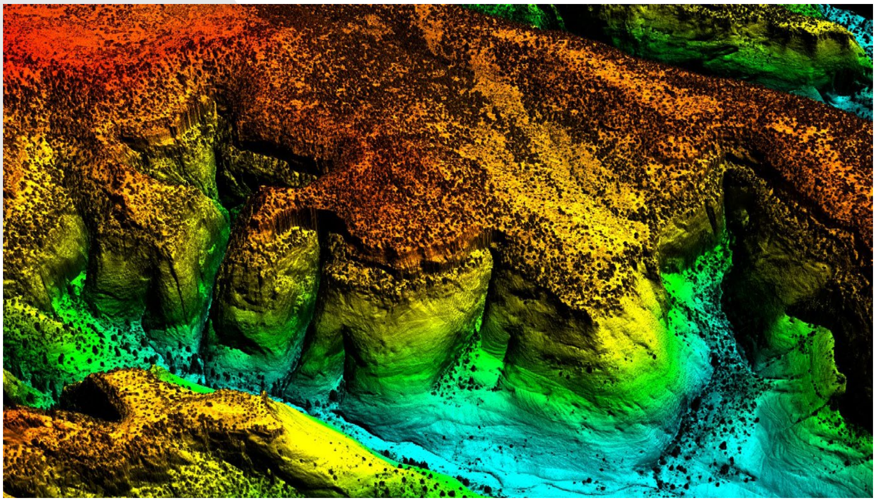
Key Differences Between Aerial Lidar Approaches

There are technical differences between single photon and Geiger-mode lidar, but together they represent a denser and higher-altitude option when compared to conventional, linear mode lidar systems.

Linear mode lidar can be described as one-to-one, in that a single laser pulse transmits a single spot image received at the single anode. Single photon and Geiger-mode lidar sensors both collect as one-to-many, starting as a laser pulse, and projecting as an array of outlet beams onto the target and detecting measurements at the receiver.

Linear mode lidar is collected utilizing a scanning pattern, continuously collecting points at altitudes of up to 5,000 meters but typically closer to 3,000 meters. The result is highly accurate data, with density commonly in the range of 1-8 points per square meter.

Single photon and Geiger-mode lidar data can be collected faster by operating at higher range of altitudes, between 3,000 and 10,000 meters. Unlike the patterned flights of the linear collections, single photon and Geiger-mode sensors operate like that of a laser-based digital camera. The laser beam is diffracted through an optical element to hit the target as a spot array, using a lower laser



Courtesy of Woolpert

Linear mode lidar was used to collect this image of Zion National Park.

energy requirement and providing a surface model with a density of approximately 25 points per square meter.

Linear mode lidar can incur more time for data collection and typically produces much less density than what is common with the single photon and Geiger-mode systems.

Woolpert is familiar with the current range of sensor platforms, having worked with nine different lidar sensors from three manufacturers in the last year alone, spanning projects across various regions, terrain, and near-shore environments across the U.S. and overseas.

The linear collections have included the Leica ALS 80, which has been employed for the majority of the firm's recent U.S. Geological Survey (USGS) 3D Elevation Program (3DEP) projects; the Optech Galaxy, which was used to collect data in the San Juan Mountains in Colorado; and the Riegl Q780i, which was used to map the Kuskokwim Delta in western Alaska. Woolpert also used the Leica SPL100 Single Photon Lidar System to collect data over 3,700 square miles in South Dakota.

Our exposure to a variety of lidar sensors used for multiple projects has provided us a firsthand perspective as to which sensors are the most appropriate per the project needs.

Testing, Building Toward the Future

The USGS is in the process of evaluating single photon and Geiger-mode lidar for use on 3DEP projects. The 3DEP initiative aims to systematically collect enhanced elevation data via lidar over the conterminous U.S., Hawaii and U.S. territories, along with a mix of lidar as well as interferometric synthetic aperture radar (Ifsar) in Alaska.

As part of that evaluation, the USGS has collected data with both single photon and Geiger-mode sensors, and tasked Woolpert and Dewberry with collecting, processing, and analyzing that data to help gauge how useful this data could be to meet 3DEP requirements.

The USGS and the National Oceanic and Atmospheric Administration (NOAA) recently awarded Woolpert a project for collecting the Big Island of Hawaii that will expand the use of single photon lidar data in support of 3DEP.

The firm intends to collect this data with the Leica SPL 100 Single Photon Lidar System, leveraging this technology's faster collection capabilities to maximize the available windows of clear skies.

This project will further test the capability of the single photon lidar technology.

Looking Ahead 3-5 Years

As lidar technology advances, the industry appears to be moving more toward increasing functionality via multiple lidar approaches instead of eliminating methods of acquisition.

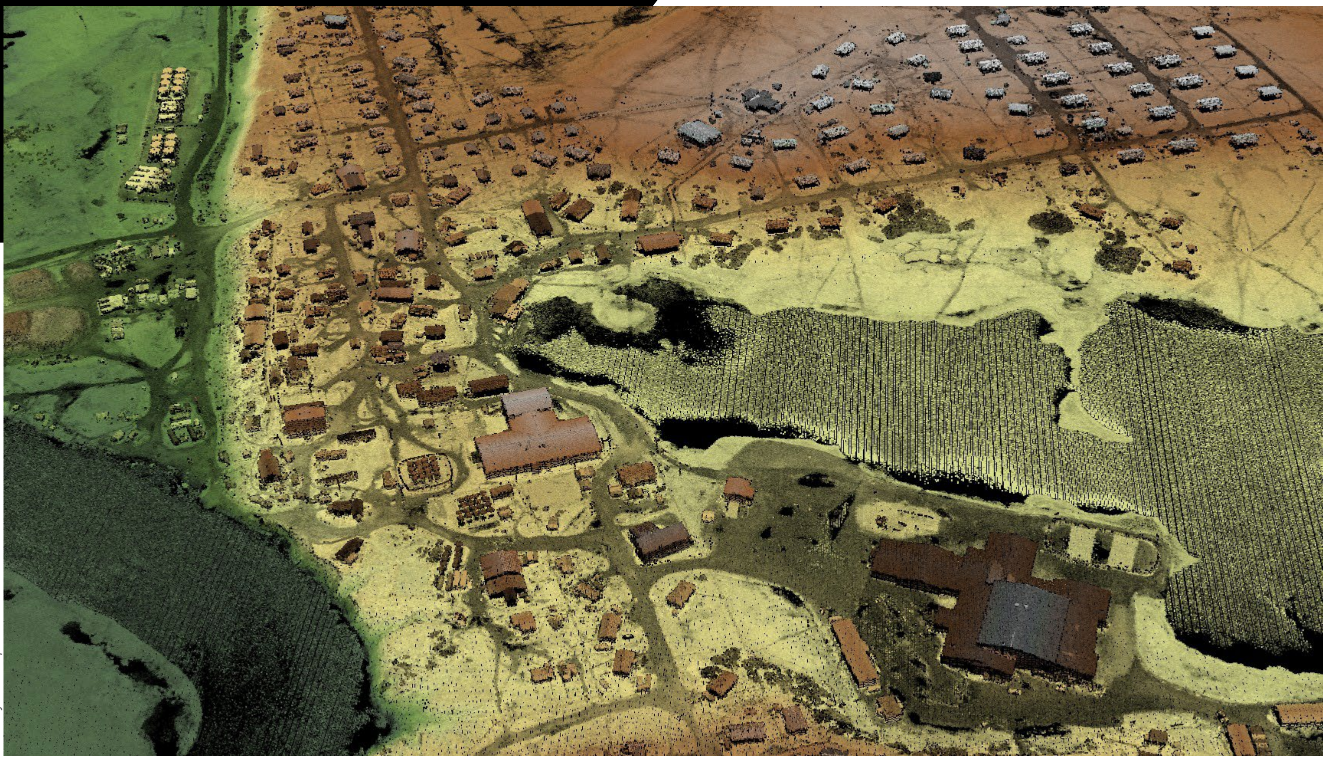
In the next three to five years, I believe not only will we see the maturation and implementation of single photon and Geiger-mode lidar technology for large-scale projects in support of 3DEP, but we also should see more specialized sensors develop as the demand for data increases.

We also should expect the continued advancement of high-altitude, wide-area linear mode sensors with improved as well as unique capabilities, buoyed by the continued development by sensor manufacturers.

In addition to these high-altitude aerial lidar sensors, the need also will remain for low-altitude sensors for energy and transportation corridor mapping projects.

Moving forward with multiple types of sensor technology, firms will increasingly be able to provide the best sensor technology, appropriate to each project, and deliver data to meet the specific needs and budget of each client.

Jeff Lovin is Woolpert Senior Vice President and Director of Government Solutions.



Courtesy of Woolpert

This oblique image of Chevak, Alaska, portrays how water dots the town, providing a constant reminder of past flooding and the potential for future storm surges. A tidally influenced network of streams, influenced by dissipating sea ice and intensified storm activity, crisscrosses the delta.

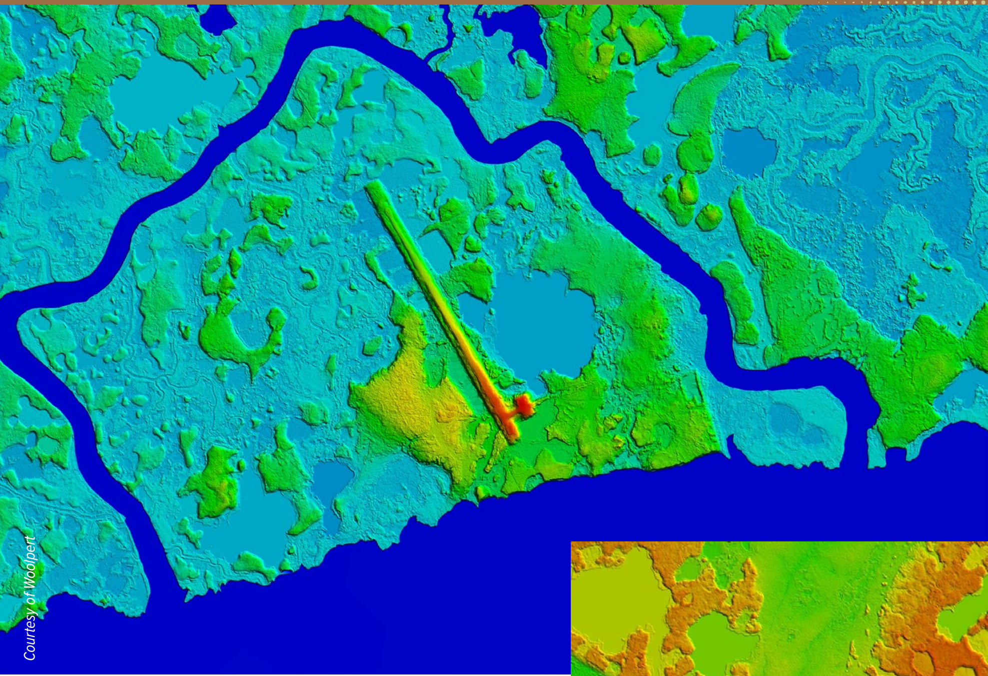
KEEPING THE THREAT AT BAY

Mapping the Alaska Coastline

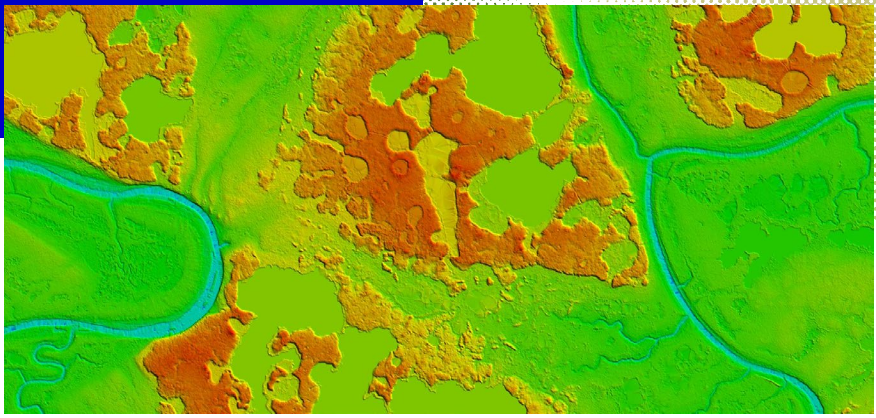
The expanse and mystery of Alaska are part of its allure, from its rugged terrain to extreme weather to incredible wildlife. But these untamed elements often come at a steep price, especially for those who live, work and raise families in some of the most remote areas of the nation's Last Frontier.

This is the case for the inhabitants of Alaska's Yukon-Kuskokwim River Delta. The approximately 25,000 residents, primarily from native Alaskan tribes, embrace a traditional subsistence of hunting, fishing and gathering in this subarctic region. However, the lifestyle regional families have cultivated for centuries has systematically deteriorated over the last few decades. The shifting topography, dissipating sea ice and intensified storm activity have caused consistent flooding and habitat loss, and restricted access to, from and within the region. The Bering Sea has battered the coastline, forcing residents to

BY MIKE **MEISER**



This digital elevation model of the village of Newtok, Alaska, shows the proliferation of inland water. The linear feature to the right is a runway, which eventually will be overtaken by the sea. Subsidence, erosion and melting permafrost have forced Newtok residents to begin relocation efforts.



This digital elevation model of a portion of the Yukon-Kuskokwim River Delta was created in part using a threshold-based, object-oriented extraction technique developed by Woolpert and based on lidar intensity imagery, 4-band imagery and digital elevation models.

abandon their homelands to avoid being submerged in the icy waters.

To find a solution to this growing, time-sensitive challenge, in 2016 the U.S. Geological Survey (USGS) contracted with Woolpert and partner Kodiak Mapping Incorporated (KMI) to collect Quality Level 2 (QL2) lidar data over areas of the Yukon-Kuskokwim River Delta region to provide precise, constructive information upon which to develop a plan of action to address the needs of the region.

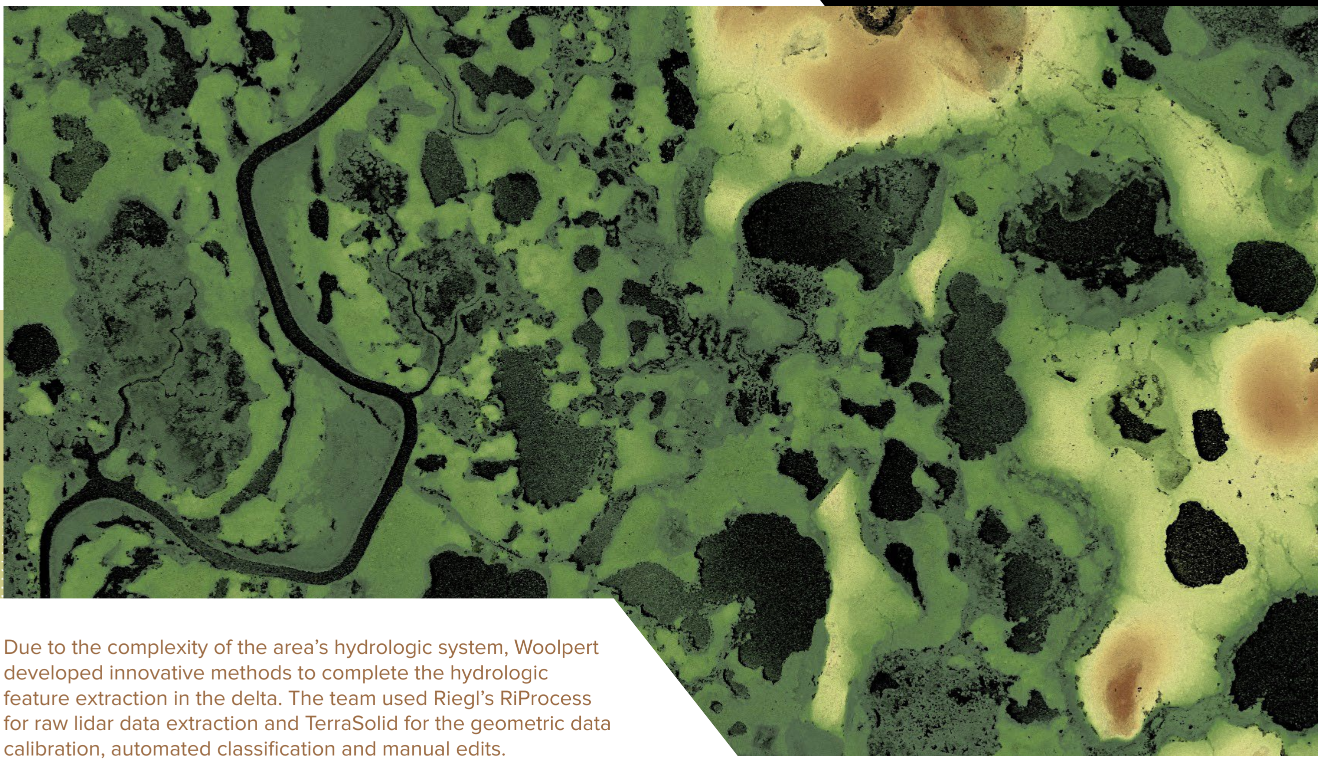
Defining the Relentless Environment

Living in the Yukon-Kuskokwim River Delta has never been easy, but there was a balance and a consistency upon which the locals relied. However, deteriorating delta conditions have eroded that stability and adversely affected nearly every aspect of life in the region.

The town of Newtok, for example, illustrates the plight of many towns on the Yukon-Kuskokwim River Delta. The community of more than 300 is located almost 100 miles west of Bethel, Alaska, which is the closest sizeable city. That mileage is measured as the crow flies.

Newtok tops the list of communities facing the probable, if not imminent, need for relocation due to recurring flooding and loss of usable land. Subsidence, erosion and melting permafrost have forced residents, who had a median age of 22.8 according to the most recent U.S. Census data, to begin relocation efforts. However, picking up an entire community and moving it to a new site is no simple task, no matter how good the plan, how developed the infrastructure or how young the residents. Newtok is gradually re-establishing itself in Mertarvik, without an established public infrastructure, airfield or emergency response plan.

Ironically, the environment upon which the Yukon-Kuskokwim River Delta residents has relied is helping to facilitate these life-altering issues. The 50,000-square-mile delta is located on the coast of western Alaska. The terrain is extremely flat, measuring only 3 to 4 meters above sea level in most places, and is especially vulnerable to storm surges from the Bering Sea,



Due to the complexity of the area's hydrologic system, Woolpert developed innovative methods to complete the hydrologic feature extraction in the delta. The team used Riegl's RiProcess for raw lidar data extraction and TerraSolid for the geometric data calibration, automated classification and manual edits.

Courtesy of Woolpert

where inundations have exceeded 30 kilometers inland.

Thousands of lakes and small ponds, and a tidally influenced network of streams crisscrosses the land. Thawing permafrost oversaturates the tundra, causing runoff and floodwaters to breach the high ground between ponds and rivers. New wetlands emerge, pockets of subsidence dot the land and the shoreline suffers from frequent erosion. Season to season and year to year, the terrain is changing.

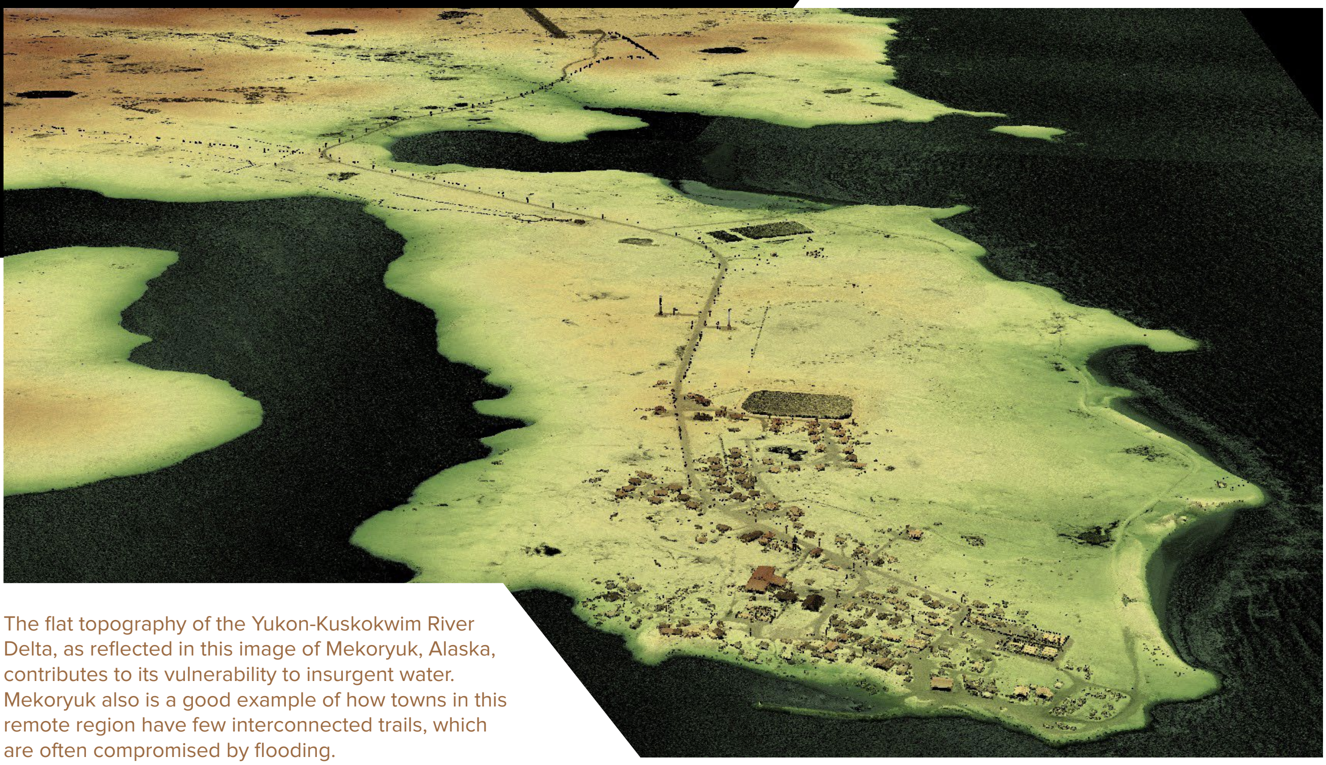
Regional warming also has caused significant melting of the area's sea ice, which acts as a natural flood and weather barrier between the Bering Sea and the delta. The combination of diminished protection from the sea ice barrier, rising average sea levels and the flat topography leaves the region extremely susceptible to flooding. The warming trend responsible for the melting sea ice is expected to continue and, with it, increasing the likelihood of future flooding.

"The combination of diminished protection from the sea ice barrier, rising average sea levels and flat topography leaves the region extremely susceptible to flooding."

Further contributing to the swelling tides are notable increases in Bering Sea storm activity—both in frequency and fury. With each storm comes the threat of storm surges, copious precipitation, wind damage and irreversible erosion. The storms battering the coast are gradually whittling away at the remaining landmass.

Mapping a Solution

The Alaskan government has collected aerial imagery and mapping data across the state for many years. Most recently, the state employed interferometric synthetic aperture radar (IfSAR) technology to capture 5-meter elevation data across Alaska's interior. Small pockets of high-resolution lidar also were flown in the Yukon-Kuskokwim River Delta region, proving high-quality lidar to be a very effective tool for analysis.



Courtesy of Woolpert

The flat topography of the Yukon-Kuskokwim River Delta, as reflected in this image of Mekoryuk, Alaska, contributes to its vulnerability to insurgent water. Mekoryuk also is a good example of how towns in this remote region have few interconnected trails, which are often compromised by flooding.

However, much of the existing elevation data was insufficient for detailed analysis of the delta due to the complex nature of the coastline, where a 6-inch elevation change is significant. Continued flooding intensified the demand for high-resolution lidar to assist with infrastructure and relocation planning, as well as wildlife habitat monitoring.

Seeing this need, and using the input of several state and federal agencies, in 2016 the USGS tasked Woolpert with acquiring QL2 lidar data over the most populated and imperiled territory in the delta. KMI, an Alaskan-owned and operated company, teamed with Woolpert to provide the lidar data acquisition and ground control services for the fast-track project. The project's 1,667-square-mile area of interest was located between the Yukon and Kuskokwim Rivers and included the threatened communities of Hooper Bay, Newtok, Chevak, Scammon Bay, Emmonak and Mekoryuk.

Since native Alaskan communities are known for their careful land stewardship, the team acknowledged that public buy-in would be critical to the collection's success. Prior to the lidar data acquisition, Woolpert assisted with a public outreach campaign to provide delta-area residents with information about the project's goals, technology and benefits, while also explaining the necessity and function of the survey crews. The project team's communications also paved the way to safe and convenient locations for base stations and survey checkpoints.

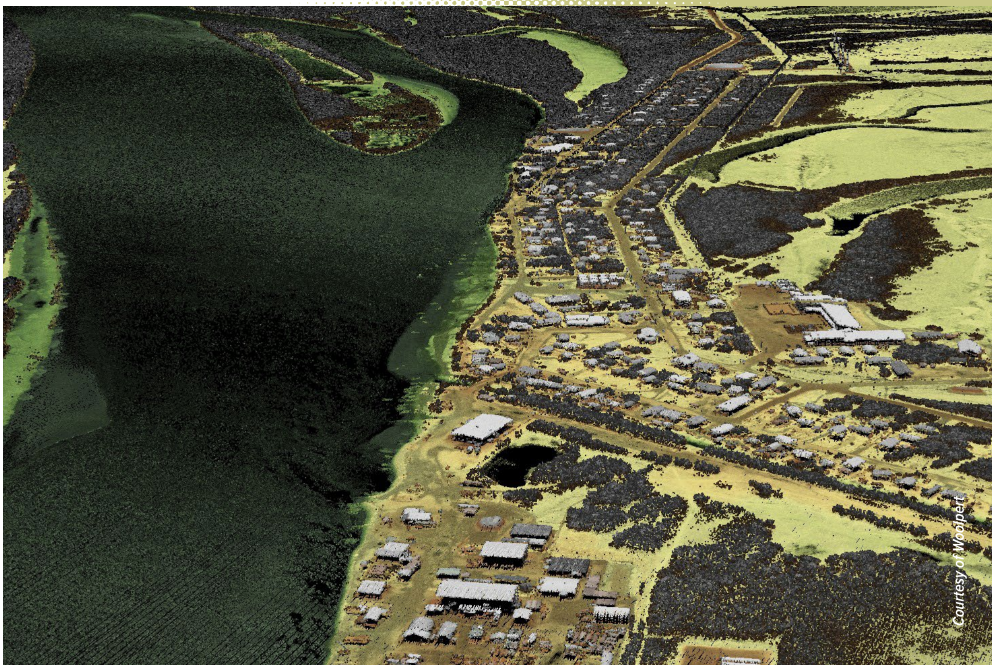
The flight crews established an operational base camp at Bethel, which is the primary hub community of the Kuskokwim region. Secondary base stations were established in communities throughout the area of interest. Alaska weather conditions dictated an abbreviated flying window, and the Woolpert/KMI team set out to acquire as much data as possible during the extremely short season—acquiring the data over just 48 days.

For the acquisition, the team used a Riegl LMS-Q780 lidar sensor mounted on a C-182 Katmai aircraft. Optimized for a 60-degree field of view, the sensor's rotating polygon mirror produced evenly spaced points and an equally dense laser footprint pattern on the ground. Flying at a height of 2,100 meters above ground level and at a speed of 110 knots, the lidar employed a pulse repetition frequency of 400 kHz. The team also used an 80-megapixel RCD30 digital camera to acquire 4-band red, green, blue and near-infrared imagery data simultaneously with the lidar.

Ideal data collection conditions are hard to come by in Alaska, and this acquisition effort was no stranger to challenges. The remoteness of the project area required very careful planning for fueling, base station placement and surveying. Tidal changes affected the timing of flights, and the short autumn season prior to a snowy winter left an abbreviated window for acquisition. Heavy cloud cover and rain halted the lidar data acquisition for over a month but did not cut short the overall acquisition effort.

The team hit its available window, completing the lidar mapping acquisition within a month and a half, and then embarked on a ground survey to support the aerial data acquisition. The survey crews established reasonable and evenly distributed checkpoints at communities throughout the area of interest, eliminating the need for helicopter access and special-use permits.

During the lidar data acquisition, quality assurance/quality control (QA/QC) was conducted on all incoming data to ensure thorough coverage and adherence to all USGS specifications on point density and distribution. The Woolpert team used Riegl's RiProcess for raw lidar data extraction and TerraSolid for the geometric data calibration, automated classification and manual edits. Due to the complexity of the area's hydrologic system, the firm developed innovative methods to complete the hydrologic feature extraction. The resulting method, which was based on the lidar intensity values and 4-band imagery, used a threshold-based object-oriented extraction technique: 2 acres for lakes and ponds, and 30 meters nominal width for streams and rivers. This massive undertaking required a substantial amount of manual quality control.



This oblique image of In Emmonak, Alaska, illustrates the proximity of residents and infrastructure to the Bering Sea. In this small fishing village, like in towns throughout the delta, the combination of diminished protection from the sea ice barrier, rising average sea levels and the flat topography leaves the delta region highly susceptible to flooding.

> "The highly accurate elevation data was made publicly available and is supporting agencies at the local, state and federal levels."

Finding Success

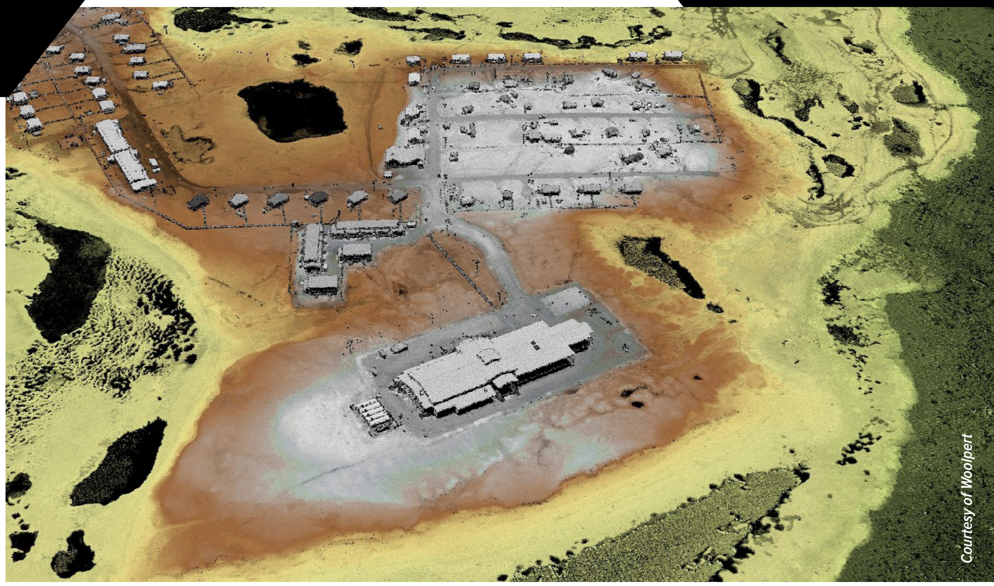
The result of the acquisition was extremely accurate lidar data of the Yukon-Kuskokwim River Delta. In a typical lidar project, the distance between lidar points is 0.7 meters with 2 points per square meter collected on bare-earth/open-terrain surfaces. The accuracy of Yukon-Kuskokwim project's data was required to be 10 centimeters root mean square error (RMSEz), and Woolpert's data came in "well below the required specification."

This highly accurate elevation data was made publicly available by the state of Alaska (maps.dggs. alaska.gov/elevationdata/) and is supporting agencies at the local, state and federal levels, allowing them to better evaluate the locations of communities at the greatest risk of flooding and inundation. In villages such as Emmonak and Scammon Bay, the Federal Emergency Management Agency (FEMA) is developing enhanced evacuation and emergency response plans based on the data.

The Alaska Department of Natural Resources Division of Geological and Geophysical Surveys (DGGS), the Western Alaska Landscape Conservation Cooperative, and a variety of other agencies are reviewing the lidar data to better support coastal flooding and storm surge mapping. These applications will help communities to quantify their risk of inundation and identify safer locations for community building.

The Yukon-Kuskokwim River Delta region also is home to the Yukon Delta National Wildlife Refuge, the second-largest refuge of its kind in the United States. The refuge also has one of the largest concentrations of waterfowl in the world, the refuge's habitat health is of global importance. The United States Fish and Wildlife Service (USFWS) is using the lidar elevation data from this project to track habitat changes, better understand waterfowl habitats and predict future movements. USFWS officials also are using the lidar data to pinpoint changes in topography that can impact water chemistry, affect sensitive salmon populations and alter migratory wildlife patterns.

Since every storm surge, flood or other topography-altering event damages and sometimes destroys public infrastructure, there are efforts underway to design and implement more sustainable trails, stronger infrastructure and more resilient public works systems throughout the delta. Three-dimensional designs based on this elevation lidar data are helping engineers to envision and create more stable and longer-lasting infrastructure components.



With more than 1,100 residents, Hooper Bay one of the most populated areas of the Yukon-Kuskokwim River Delta. This digital elevation intensity model shows Hooper Bay's buildings and roads surrounded by lakes and small ponds.

Conclusion

The lidar data of the Yukon-Kuskokwim River Delta has proved and will continue to prove to be a highly effective tool for assessing the topography of the region. In the case of Newtok, community leaders, government officials and private contractors are using the lidar data to select locations best-suited for future infrastructure placement and the long-term viability of the community. This data provides rich, highly accurate topographic information to help residents throughout the delta community better understand its changing environment.

This project illustrates the overarching purpose of the geospatial community, which is to protect and preserve land and life through the application of knowledge and technology. Through efforts such as these by the USGS—which plans to add this lidar data on its National Map Viewer at viewer.nationalmap.gov/launch/—as well as other government agencies and geospatial firms, we can improve the quality of life for people all over the Earth.

Mike Meiser, CMS, PMP is a geospatial project manager and associate at Woolpert, where he has worked for 12 years. Meiser is a Certified Mapping Scientist with a specialization in lidar and a Project Management Professional, as well as a member of the American Society for Photogrammetry and Remote Sensing.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PHOENIX LIDAR SYSTEMS

Excellence in UAV integration

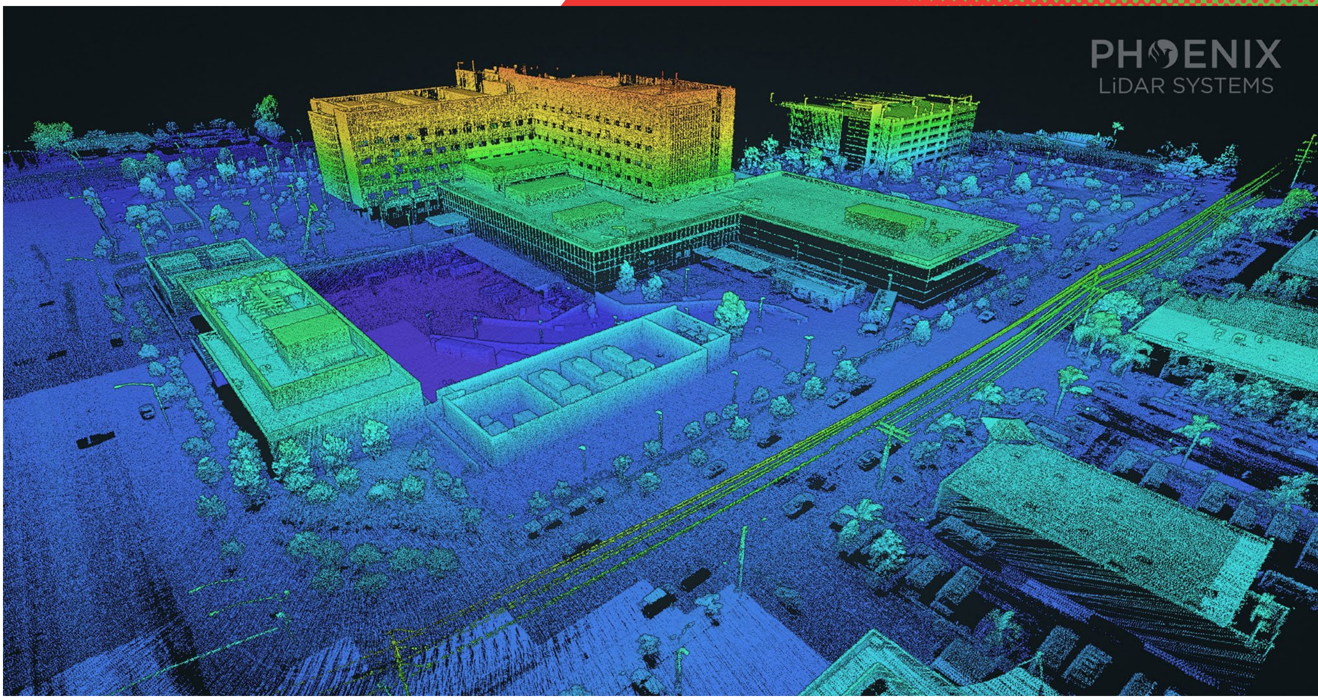
Managing Editor Stewart Walker met with Phoenix LiDAR in their Los Angeles office, profiling a young company that leads the market in the integration of LiDAR sensors with UAVs

Grayson Omans founded Phoenix LiDAR in 2012 and built a team that would develop the industry's first commercial UAV LiDAR system.

Amidst the excitement of UAVs and their rapid development as a disruptive technology in our geospatial world, *LIDAR Magazine* is pleased to take a closer look at a team driving such innovation. Phoenix LiDAR Systems, the first to offer commercial UAV LiDAR, hails from the Palms neighborhood in Los Angeles. Located just a stone's throw from big names such as Sony Pictures, NPR, and the NFL, Phoenix's roots indeed echo the entertainment ideals of its neighbors: CEO Grayson Omans started his UAV flying days hovering cameras over actors on film sets, and as UAV and LiDAR technology became more affordable for commercial use, he saw an opportunity and shifted his UAV payload from imagery to lasers.

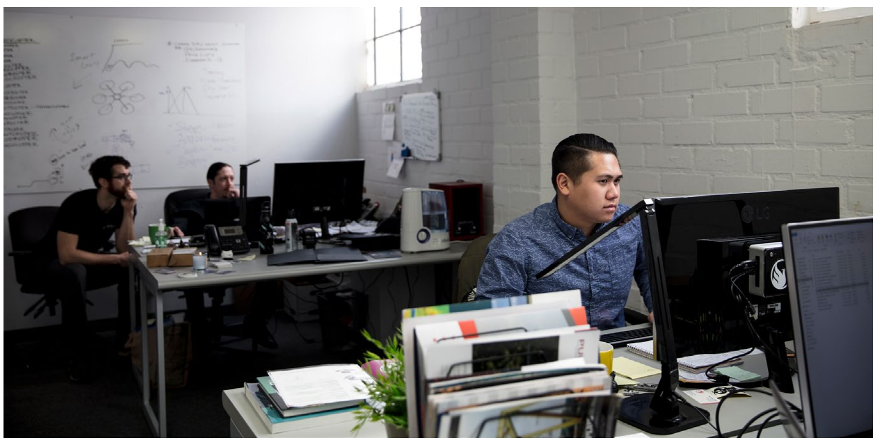
The move from aerial filming to aerial mapping was a daunting task, the first requirement being reliable control and tracking of the UAV. Enter Dr. Benjamin Adler, co-founder and researcher who wrote his Ph.D. thesis on autonomous

BY STEWART **WALKER**



This point cloud capturing a rural hospital and nearby utility power lines was generated in LiDARMill, Phoenix's post-processing automation platform.

UAV mapping. Working with a lot of fishing wire, Grayson and Ben developed a reliable method of controlling the UAV without risk of it flying away with their equipment. They then sought to borrow $52,000 of LiDAR equipment from none other than Velodyne LiDAR, a big request coming from a tech startup comprised of two people. To its credit, Velodyne agreed, sending Dr. Wolfgang Juchmann to Southern California to witness the test flight. A week after his wedding, and to his young wife's eternal chagrin, Grayson postponed his honeymoon and worked with Ben to prototype what would become the industry's first commercial UAV LiDAR system—needless to say, it featured a Velodyne sensor. Business ensued and the rest is history. Grayson's candor and humor on this

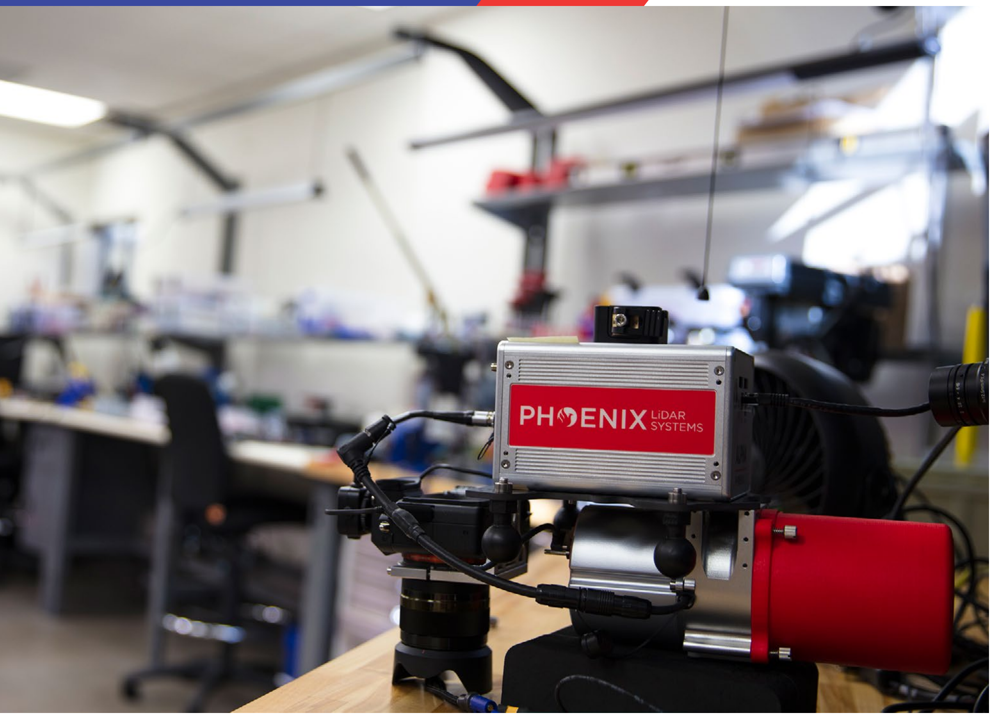


Phoenix LiDAR began in Los Angeles with two people and has expanded to 26 team members around the world.

topic characterized our discussions and the insights into the UAV LiDAR world that emerged.

I spent several hours with Grayson, learning the Phoenix story first hand from him and his sales and marketing directors, Eric Agnello and Vu Nguyen.

Grayson has a business degree from Cornell, though his father was a mechanical engineer, and the yen to take things apart and reassemble them rubbed off. Grayson began to build UAVs as a hobby and developed experience that would later inform his business decisions, including the opportunity created by combining an aircraft with sensors and software. He and Ben, who built their software development



This Phoenix Alpha system captures both LiDAR and photogrammetry data, and was customized to include an integrated high-definition DSLR camera.

team in Hamburg, Germany, concluded that UAV autonomy is the holy grail for their fledgling industry, and proceeded accordingly. Combining autonomous UAVs with mapping necessities such as LiDAR sensors, high-definition cameras for photogrammetry, and a host of other equipment, appeared to Grayson as a powerful business case.

The Business

The company was founded as Phoenix Aerial Systems in 2012, in recognition of the mythical bird, but was renamed as Phoenix LiDAR Systems in 2016 to reflect more accurately its focus on LiDAR. Expanding to its current location in 2017, the team is already outgrowing its new space. Phoenix has 26 full-time employees, including some in Hamburg and around the world, and 10 consultants. Its team boasts many accomplished people with years of experience in their respective, and sometimes very specialized, fields and it has sold hundreds of systems to more than 100 customers in many countries, ranging in size from private surveyors to national governments. Phoenix's clients work in many industries, including power and utilities, forestry, mining, oil and gas, urban development, and more. Phoenix has established a worldwide distributor network and is engaged on expanding it—the knack of channel management is a subtle one when products are complex and require skills such as piloting and data processing.

To fund Phoenix's research without the venture capital investment that is so common for tech startups, Grayson founded a second company, BrushlessGimbals.com, which profited by building components for stabilizing cameras in flight, as an alternative to legacy servo-based systems. The support it provided was especially important, since Phoenix's systems were not yet legal in the US: this was well before the Section 333 waivers that the FAA began granting in 2014, and even further before the current Part 107 regulations that opened up much of the drone market in the country. Grayson sees these changes as key to his business and that of many others in the UAV space.

Despite the fact that expensive components strain margins, Phoenix continued to grow organically and now offers a spectrum of systems, each tailored for a different set of specifications, ranges, densities, etc. The automotive market is enormously bigger than the airborne, and is the leading driver in LiDAR sensor development. Sensors suitable for UAV flights are expensive, though systems are expected to become lighter, more accurate, and less costly, due to R&D for the automotive segment. Though he's gone to great lengths to minimize weight, Grayson thinks his systems are still heavy and labors on further reductions while also increasing power.

Innovative "Firsts"

Phoenix has used its head start in UAV LiDAR to its advantage, developing a number of other industry "firsts." In 2013, it launched a feature to enable clients to view their LiDAR data in 3D while the system was airborne, reducing acquisition errors such as flying too high—or, more embarrassingly, forgetting to turn on the LiDAR sensor. In 2015, it launched the industry's first fixed-wing UAV LiDAR system and,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-Scalable Solutions
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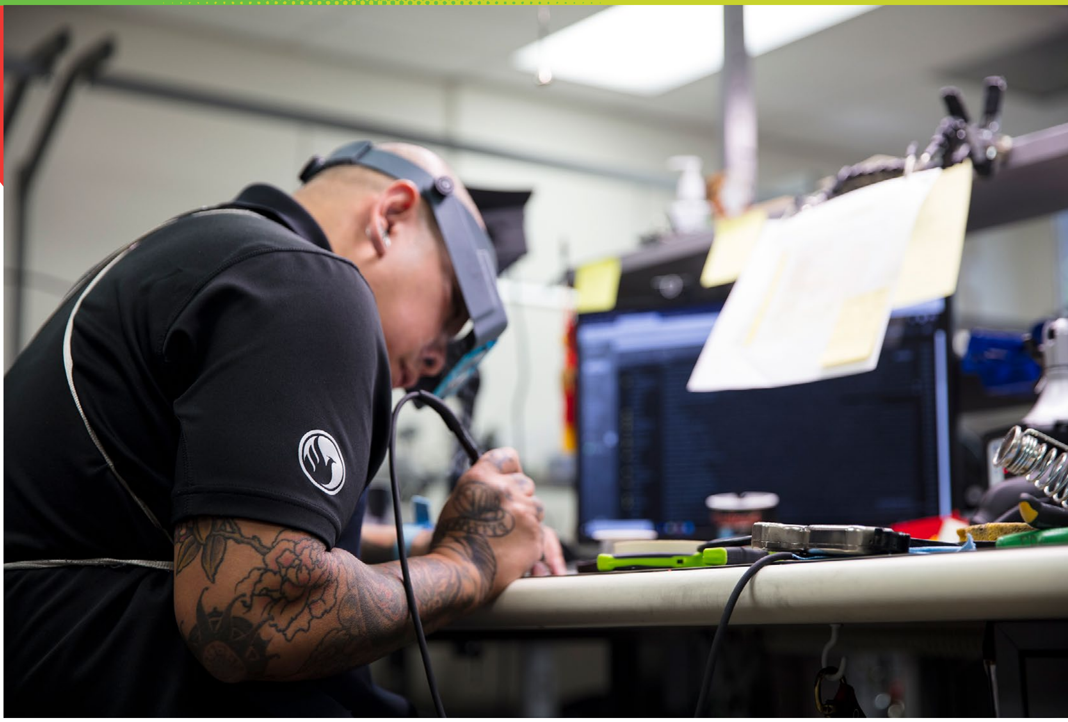
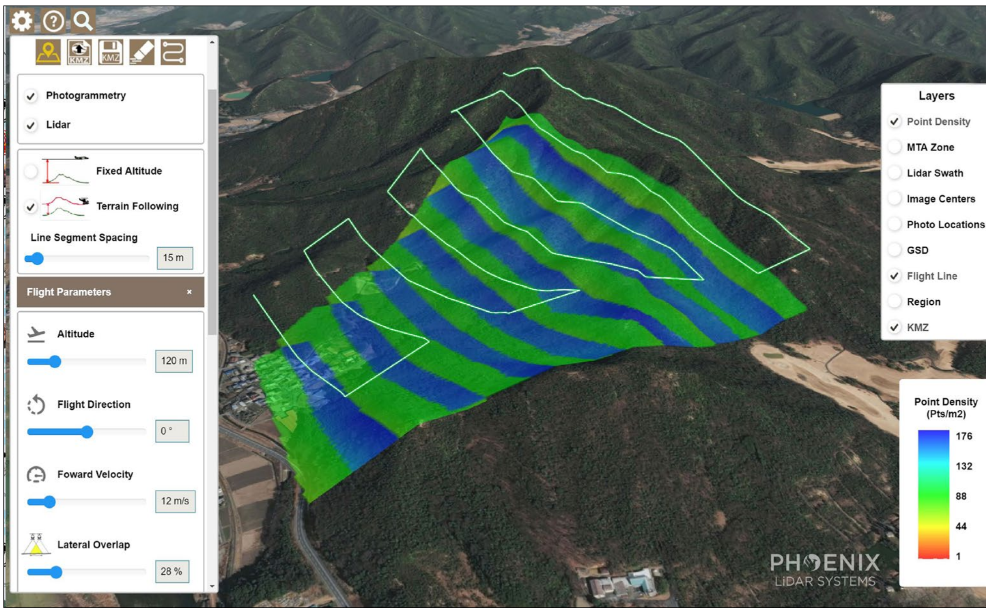


The Phoenix team builds every LiDAR system in the United States.

in 2016, the first dual fixed-wing and VTOL system. Both took advantage of the speed and stability of a fixed-wing aircraft and the latter also enabled vertical take-off and landing for runway-deprived surveying environments. In 2017, Phoenix announced the industry's first cloud LiDAR post-processing platform, which they call LiDARMill, and the first UAV LiDAR flight planner, a free tool which helps users plan terrain-following autonomous flights that optimize LiDAR data quality. Users can then upload that data directly to the UAV.



The Phoenix Flight Planner is the industry's first tool that helps users plan terrain-following autonomous flights that optimize LiDAR data quality. Users can then upload that data directly to the UAV.

The Technology

The Phoenix team explained that many of their clients start with photogrammetry, but eventually seek LiDAR to address some of photogrammetry's limitations. Unlike its counterpart, LiDAR is able to map the ground underneath dense vegetation and can work in situations with low or no light. Though they seemingly compete, Grayson views UAV photogrammetry as a complement to UAV LiDAR. Both are powerful tools that address different parts of the surveying and mapping process. Professionals should perceive the technologies as complementary and use them accordingly. If the full potential of LiDAR is to be reached, however, night flying and BVLOS must become possible, though they are currently prohibited by regulation.

Phoenix LiDAR team members assemble a RANGER system on a Vapor 55 UAV.

In building their first systems, Grayson and Ben's research concluded that not only is a large UAV necessary to support the weight of a LiDAR sensor, but for survey-grade reliability, each system would also need an IMU and GNSS equipment of sufficient caliber and durability to withstand the vibration and general environment of an airborne drone. Systems would also need to include electronics, data recording hardware, software, and an assortment of other sensors that clients might need for their projects. Integrating it all and keeping the weight low has been an ongoing objective of their research since 2012.

Phoenix's custom electronics box, which they call the navigation box or "navbox," serves as the system's "brain," and can be used to connect a variety of accessories, such as cameras that record RGB, multispectral, hyperspectral, and thermal imaging. These sensors and others, integrated based on client requirements, connect to the navbox, saves the data and can broadcast it for live transmission to operators or remote viewers. The resulting data comprises millions of laser points in a raw point cloud that often encompasses a 360° viewing field.

Customized LiDAR

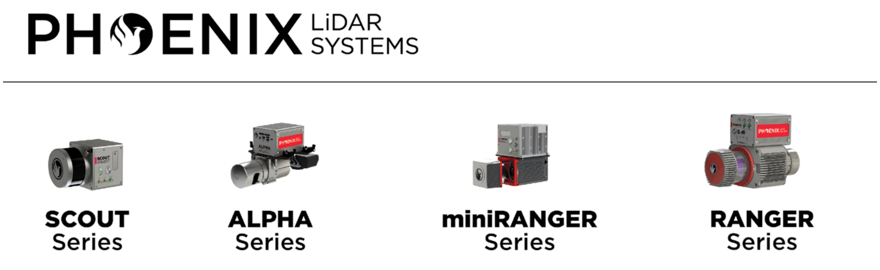
Flexibility is Phoenix's battle cry—the key, Grayson contends, to their success. They design signal routing boards from scratch and go to the very root of the GNSS cards that they build into their navboxes. This control of detail enables Phoenix to cater to almost all requests. Their boards can handle gigabit Ethernet cameras, for example global shutter, RGB, hyperspectral, plus LiDAR. Every customer is unique, so customization is worth a great deal to the team, which modifies their standard systems as needed. For example, Phoenix's miniRANGER system, which includes a LiDAR sensor, a Phoenix navbox, an IMU, and a UAV, can be upgraded to include dual RGB cameras, which expands the scan swath to a surprising 250-meter swath, all on a UAV flying within the rules.

Because the key to its success is customization, not only can these systems be integrated with a host of sensors based on client need, but most Phoenix systems are also modular and can be moved between platforms as needed: from UAV to aircraft, vehicles, or backpacks. This modularity maximizes the value of each system, which is often a major investment for clients.

Since most of their LiDAR systems feature custom integrations, Phoenix sends teams out several times a week to test every outgoing system for accuracy and calibration. Phoenix's calibration site in northern Los Angeles features a huge concrete dam with structures of varying shapes to facilitate the process.

Equally Important: Post-Processing

After LiDAR acquisition comes the equally important step of post-processing. While they've made great progress on the flight planning and acquisition side, Phoenix continues to build new products, most of which are the direct result of client feedback. Knowing that the barrier to UAV LiDAR entry isn't only the high upfront equipment cost, but also the expensive software and engineering work required to process the data, Phoenix launched the industry's first cloud post-processing automation platform, LiDARMill.



Phoenix offers a suite of flexible systems that can be customized to suit each client's projects.

The platform, currently in beta testing, tackles the basics of post-processing in the cloud for organizations that don't yet have their own post-processing setup. LiDARMill covers point-cloud calibration, from trajectory refinement to ICP (iterative closest point algorithm), makes flight line adjustments, and fits strips of data together. The later post-processing steps, such as denoising, filtering, and classification, are much easier with a calibrated point-cloud. As a result, companies can quickly scale, taking on more projects and growing their operations.

The Hamburg crew has created a remarkable software stack, which works with large and dense point clouds. As a result, Phoenix can deal with lower quality IMUs shored up by high quality laser shots. The company is almost there in terms of "processing the cloud in the Cloud." While it seeks to save money for its clients, Phoenix has no aspiration to take the place of specialist post-processing software, which will continue to play an important role in LiDAR mapping, but rather, to simplify and automate as much as possible.

The Standard Phoenix Systems

Phoenix offers a suite of customizable systems. The Scout is billed as an entry-level system and consists of a Velodyne puck sensor attached to a Phoenix navbox. The system is typically mounted to a UAV such as the DJI M600, and is often used to conduct research surveys and map basic infrastructure. Its older "sibling" is the Alpha Series, which is also often paired with a DJI M600 and features a mid-grade Velodyne sensor. This 32-laser sensor rotates as it captures the world in 360°.

The miniRANGER boasts a powerful Riegl sensor that can accept up to five returns per pulse. Like the others, it can be integrated with many UAVs, though the DJI M600 is a popular choice. The RANGER system features a Riegl VUX, which is designed for the most demanding mapping applications, and offers the best combination of range, density, accuracy and data quality. This 1550-nanometer sensor, when paired with the Phoenix navbox, becomes the heart of a powerful payload that has few rivals in unmanned aerial mapping. It's often flown on a Pulse Aerospace Vapor 55 UAV, but has also been modified for the TerraHawk CW-30 system and others.

Phoenix's two TerraHawk systems, CW-20 and CW-30, are the industry's first fixed-wing VTOL UAV LiDAR systems. Gas and electric hybrids, these birds are Phoenix's response to customer feedback that fixed-wing systems required belly landings that endangered costly LiDAR equipment. Phoenix built these systems to take advantage of the speed and stability of a fixed-wing, while offering the convenience and protection of VTOL, which eliminates the need for landing strips, and offers a backup landing system, if needed.

In Conclusion

I was very impressed. Phoenix's expertise and commitment are evident, and their passion for LiDAR is apparent in the frequent innovations they introduce. With new products such as the Flight Planner and LiDARMill, they also demonstrate awareness that, despite all of its development, LiDAR is still a very complex technology, and acquiring and post-processing data must be simplified if the industry is to grow fast. Through the hardware and software options they offer, Phoenix takes steps to simplify and automate both the acquisition and post-processing phases.

To those who have been in the industry for a long time, it's clear that UAV LiDAR acquisition requirements cannot be addressed by merely offering single-flavor solutions; rather, systems must adapt to meet the needs of each application. Maximizing this flexibility while maintaining survey-grade accuracy will be a particular challenge to system integrators such as Phoenix, especially if the technology continues to develop as rapidly as it has in recent years. I believe it will, and based on their work, I look forward to seeing how Phoenix will help shape the UAV LiDAR industry in the years to come.

Stewart Walker is managing editor of the magazine.

Figure 1: Tectonics Mountainville NY office with the new survey van

American Trail Blazers

in New Mobile Mapping Technology

With all the new emerging technologies, established companies using traditional methods must explore ways to remain competitive. Most of us are familiar with Albert Einstein's famous quotes "Insanity: doing the same thing over and over again and expecting different results" and "Life is like riding a bicycle. To keep your balance you must keep moving." Both of these quotes (we could even call them axioms at this point) lend themselves extremely well to the geospatial and business worlds. With advances in technology, it is necessary to keep one's business balance by carefully observing market dynamics related to competitiveness, service or product pricing and overall profitability. Just doing the same old thing over and over ultimately results in declining profitability. The balance is found by investing wisely, to stay at the more profitable areas of one's offerings.

Study of an Actual Business Case

A prime case study is with the recent decision of Tectonic Engineering & Surveying Consultants (NY, USA)[1] to expand their business into the offering of very high performance mobile mapping. Early in 2017, they placed an order for a SITECO Informatica (Bologna, Italy) Road-scanner Compact[2], equipped it with a pair of FARO (Lake Mary, FL, USA) Focus[3] laser scanners and deployed it onto a newly purchased

BY THEODORE J. **HAINES** AND BRENT W. **GELHAR**

and custom outfitted van. Tectonic is the first company in USA to adopt this SITECO technology (**Figure 1**).

Tectonic offers a full spectrum of professional engineering and design services. Established in 1986, it has grown to become a multi-disciplined engineering firm and is repeatedly recognized by Engineering News-Record[4] as one of the top 500 engineering design firms. Committed to providing well-organized, thorough work, their team of over 500 is focused on delivering a timely, economical, and quality product. Tectonic had been providing terrestrial scanning for several years and with hundreds of projects under their belt and were looking for the next step up in technology. With several major agency clients in New York City embracing this technology it was a no-brainer decision that Tectonic needed to be in the mobile scanning market.

Evaluating the Options

The question that arose was how to best employ the required investment to get the greatest overall effectiveness and efficiency out of the funds being spent. With the many available mobile solutions on the market today, a long line of decisions were made, such as;

- Determining accuracy requirements, which hardware could deliver the desired engineering and survey grade performance.

Figure 2: close up view of the SITECO Roadscanner Compact with Faro scanners

- Evaluation of workflow software delivered with a system. It was quickly discovered that many available system offerings were highly dependent on additional third-party software products, not included with the hardware.
- Ensuring that the workflow also fit seamlessly into the Tectonic existing environments, consisting primarily of AutoCAD based tools and the Cloudworx suite from Leica Geosystems.
- Many questions arose to getting the required support for the application suites, not having to rely on multiple vendors.
- Finding a supplier having an actual track record with real-world experience in carrying out roadway, infrastructure and asset management survey work.
- Being able to maximize the use of systems components for other work (i.e. using the scanners in static mode also), when mobile scanning is not required.
- Robustness in the design and build quality of the overall system implementation.

Finally, the SITECO-FARO Roadscanner Compact was determined to be the best, and only, combination that really fits these criteria (**Figure 2**). While there were other highly robust competitors offering very good packages, there was nothing else as high performance yet cost effective that included a true end-to-end software workflow. So the purchase decision was made, the system configuration determined and the order placed. (**Figure 3**).

Post Deployment Discoveries

The first result of going mobile that was discovered was that the in-house drafting needs have multiplied. With field team deployment time cut down by more than 50% Tectonic had to increase its drafting capacity. Most output is still traditional flat 2D maps so to keep up with the speed of field production, Tectonic had to increase the office staff side of the equation. They also had to re-think the entire approach to work flow. Field crews required additional training to avoid picking up all the traditional information typically needed, since the mobile mapping system scanners do that very effectively. They only need to survey the few pieces the scanner does not pick up, such as inverts and monumentation. Attention was now being focused on shadow areas, fill-in, and most importantly, better attention to accuracy in ground control survey.

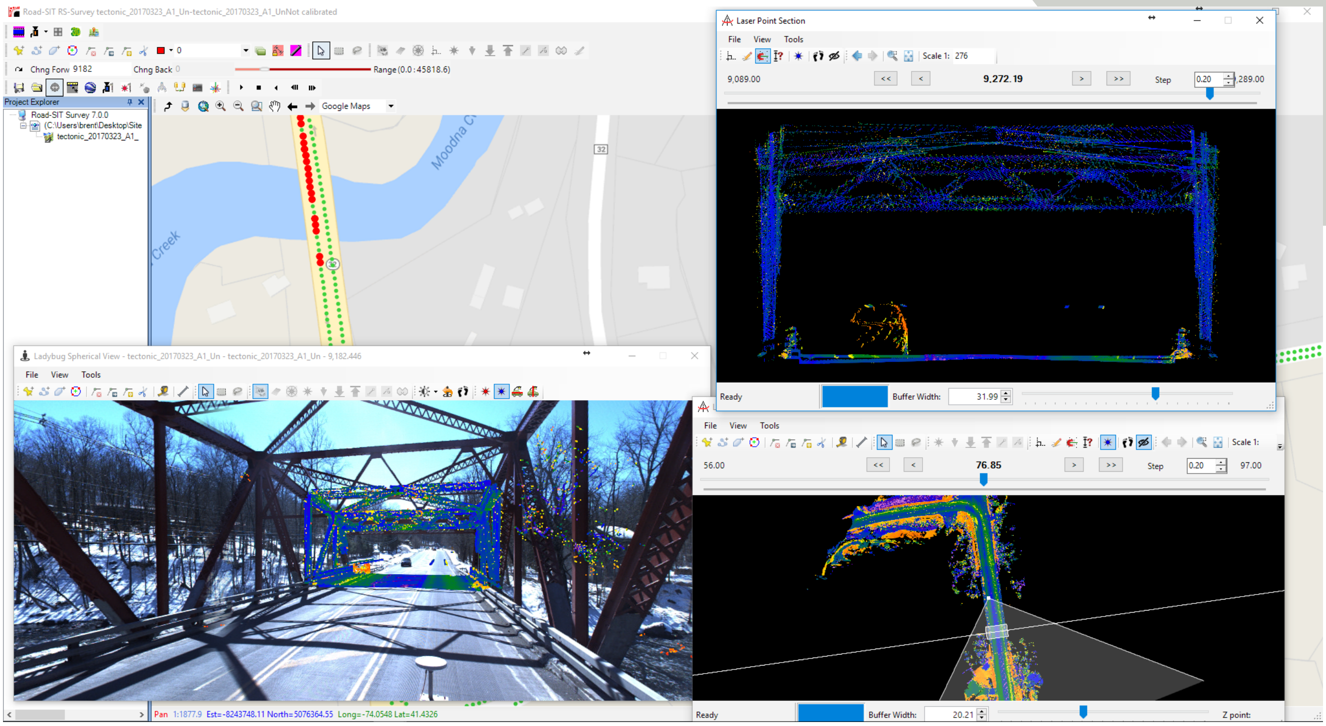


Figure 3: SITECO RS Survey analysis software sample. Clockwise from top left; Google maps view of data collection area, vertical cross section, top view horizontal section showing cross section and camera pointing position, camera view with lidar point overlay of the selected cross section)

While this may initially appear as a major disruption to the organization, the overall process has brought Tectonic into a higher sphere of efficient operations. The retraining and redeployment of staff has strengthened Tectonic's competitive edge, allowing the firm to be in a better position to win higher value projects, rather than only traditional survey where there is much more competition, eventually of course leading to price and profitability erosion.

Trailblazers

The entire process that Tectonic experienced has now effectively differentiated them as a leading edge provider of top level services. By having carefully examined all the available offerings on the market, and the surrounding support infrastructure, they have placed themselves into a very cost-effective position. Their technical decisions to select flexible hardware with multiple deployment capability (both mobile and as static scanners) maximizes the investment efficiency. The system performance, being on highest levels of data capture accuracy, can also be easily upgraded as newer scanners and other components become available on the market.

So going back to the original quotes from Albert Einstein, here is a company which has very carefully and thoughtfully embarked on a new path to differentiate itself in the geospatial services marketplace, delivering higher value products. Using the flexible instrumentation deployment concept (i.e. 3D scanners for both static and mobile mapping solutions) allows for Tectonic to have a better overall cost effectiveness of their capital investments. They are definitely not doing the same thing over and over again and are continuously keeping a strong balance by moving forward with the latest technology.

Theodore J. Haines, PLS is the Vice President and Manager of Surveying at Tectonic Engineering where he has worked for over 15 years.

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[1] Tectonic Engineering www.tectonicengineering.com

[2] Siteco Informatica www.sitecoinf.it

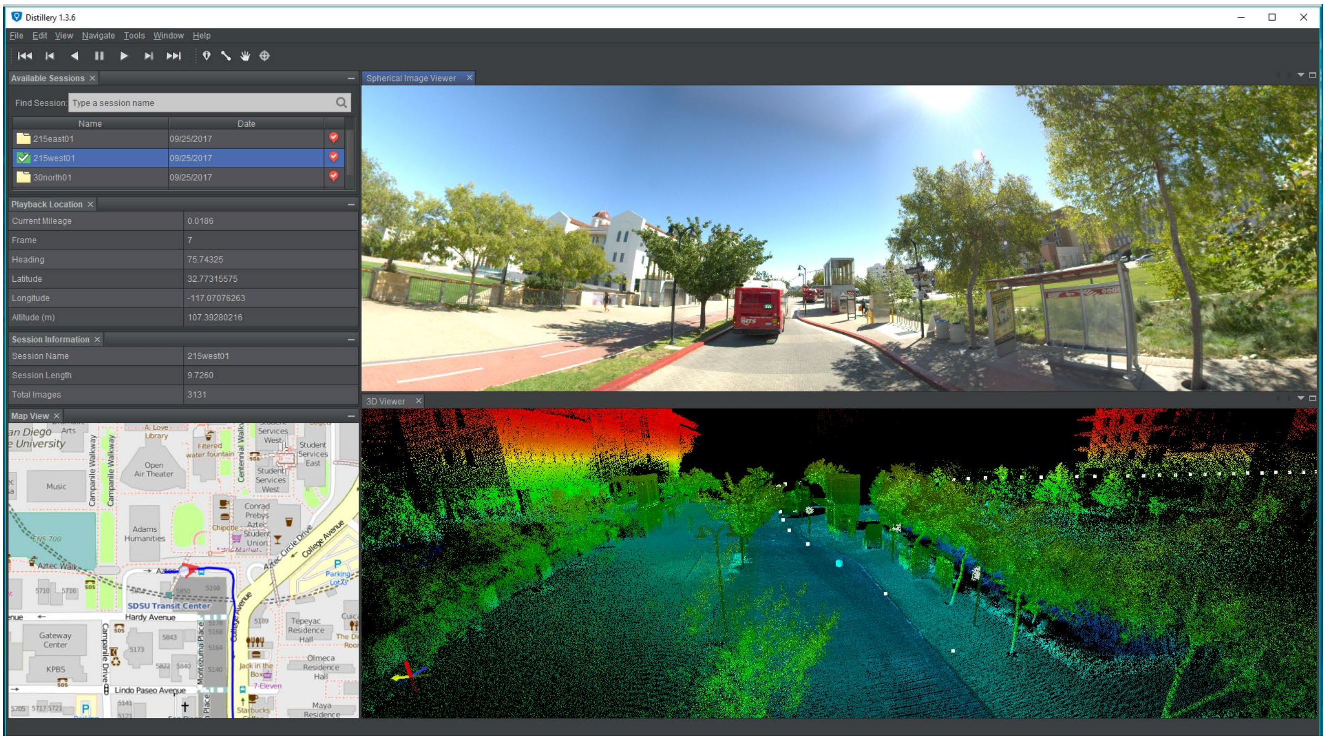
[3] FARO Technologies www.faro.com

[4] Engineering News-Record www.enr.com

FROM RAIL TO ROAD

Mobile Lidar Applications in Public Transportation

BY TIFFANY **HUNT**



The point cloud, 360° imaging, and map view are shown within Maverick's post-processing and data viewing software. Several of the assets that were extracted are shown in the dataset, including the bus stop, shelter, bench, and garbage cans.

For the San Diego Metropolitan Transit System (MTS), mobile mapping has made a significant impact on day-to-day operations. Between their light rail and bus routes, MTS serves approximately three million people in San Diego County. Managing 106 miles of track and almost 100 bus routes is no easy feat, so when MTS heard about data collection services for State DOTs they reached out to Mandli Communications (Mandli) for a solution.

The main challenge to collecting mobile lidar data on a light rail line is finding a mobile mapping unit capable of being mounted on a trolley without interrupting service or affecting travel times. This is a serious concern for MTS, as they provide over 310,000 passenger trips each weekday. Any delay to that service has a serious impact on the surrounding area.

Mobile Lidar Solution

The technology used for MTS is Teledyne Optech's mobile mapping system, Maverick. The highly portable system combines 360° imaging, high-definition lidar, and an integrated position and

Maverick mounted to a commuter train with Mandli's prototype suction cup mount. The mount is powered by a vacuum pump with an internal backup battery housed within the control box.

orientation system to efficiently collect accurate mobile data. Maverick's lidar unit collects up to 700,000 data points per second and the 360° camera captures high-resolution images using six high-quality 5-MP sensors. Weighing less than 9 kilograms, Maverick operates in a wide range of conditions and is easily mounted on a variety of platforms.

"With Maverick, we were trying to accomplish three things: bring the price down to remove barriers to entry; remove some of the complexity associated with high-accuracy mapping; and shrink the unit for deployment in different types of applications," explained Albert Iavarone, Sales Director and Business Unit Manager for Teledyne Optech's terrestrial products division.

Maverick was chosen for this project because of its portability and flexibility in mounting options: it has its own traveling case, meets weight requirements to be checked as airline baggage, and its optional four-armed vehicle mount attaches to just about any on-road vehicle's roof rack. For this rail application, Mandli developed a prototype suction cup mount, designed to attach to the windshield of any commuter train. The mount is powered by a vacuum pump with an internal back-up battery housed within the control box.

Mandli first collected lidar data and images for the light rail service with an early prototype of the Maverick in 2013. With the Maverick now available for sale, Maverick operators were asked to return and update MTS' dataset in May 2016.

Rail Applications

Data was collected along 106 miles of track in less than a day. The resulting dataset, viewed in Mandli's Roadview Workstation software, provided MTS with an accurate GIS inventory of all trackside assets, which allows them to inspect and monitor track condition from the safety of their offices. It also allows MTS to maintain an accurate inventory of assets. "Roadview [Workstation] allows MTS to find, map, and categorize everything along the right-of-way. It's helped our track team analyze work that needs to be done faster and more efficiently," said Paul Jablonski, MTS CEO, in a recent article published in Metro Magazine.

While the Track and Wayside departments at MTS were the original groups interested in mobile lidar, other departments gained interest as they viewed the data and began to see ways it could be utilized for their purposes as well. MTS Rail Training Supervisor Dave Jensen added, "Roadview [Workstation] is a perfect element for the train operator training program. We are just getting into the process of using it. It shows students all the intricacies of the system through a new lens. We can visually show students about defensive driving, what to look for in tough intersections, speed limits through certain areas, and much more. And, do it all from the classroom setting."

Bus Applications

After seeing the value in mobile lidar and 360° imagery, MTS requested Mandli return with the Maverick to collect a few pilot routes for the Bus Division in September 2017. The entire collection process took less than a day. For bus applications, transit agencies can use the resulting dataset to perform an inventory of bus stops and other assets along the routes. The imagery will be used to train new bus drivers and bus drivers switching from one route to another. Bus drivers will be able to virtually drive through their assigned route to see obstacles, tight corners, and other potential difficulties.

As early adopters of mobile data collection technologies in the public transportation industry, MTS plans to continue to utilize mobile data to manage its rail system's inventory. The agency also has plans to renew its GIS inventory when it begins operations on an 11-mile rail extension up the north coast to UC San Diego in 2021.

Tiffany Hunt has been writing professionally within the transportation industry for three years. As Communications Specialist for Mandli Communications, Tiffany enjoys researching and writing about cutting-edge technology, including advances in lidar sensors and autonomous vehicles.

For the collection of MTS' bus routes, Maverick was mounted atop a rental car.

STATIC LIDAR AS A TOOL IN SURVEY RELATED PROJECTS

Scanning of the bridge using the static scanner

> "The increased level of detail gives today's surveyor the ability to deliver a more complete and valuable product."

The surveying technology is constantly evolving with improvements in ground based collection techniques. Tripod mounted static LiDAR has become another tool in the box for the smart surveyor. The increased level of detail of LiDAR data gives today's surveyor the ability to deliver a more complete and valuable product. MA Engineering Consultants with its long history of investing in the best people and technology has added static LiDAR based services to improve the efficiency in their surveying services. Very recently, MA Engineering has performed multiple projects using static LiDAR both indoors and out with the different level of challenges. In this paper, a description of the workflow, usage of different packages, and the deliverables for two of those projects have been provided.

BY SRINI DHARMAPURI PHD, CP, CMS-LIDAR

Point cloud data of the bridge

Methodology

Static LiDAR based data collection process is ideally the same, whether the data is collected indoors or outdoors. In static LiDAR based collection, the scanner is set atop a standard, leveled tripod at a known location or can be set at a random location with a clear view of the 3D targets on known locations. The scanner can then be set to scan either very specific areas or everything within view of the scanner—including directly overhead. Current scanners have the provision of an attached digital camera, so that digital photos are taken in each of the target directions. The scanner range is an important parameter in determining the number of scans needed to get a complete coverage of a project area. After the scan is complete at a given known location, the scanner is placed at a new location and the process is repeated until complete coverage of the project site is obtained. Like aerial and mobile LiDAR, 3D targets are used to identify key locations between scans so the data can be joined together.

After the scanning is complete, individual scans are combined into a coherent scan through a process called registration. During this process, a coordinate system reference will be added to the data. The raw data product of a laser scan survey is a point cloud and all points within the point cloud have X, Y, and Z coordinates as well as laser return Intensity values (XYZI Format). If images are taken along with the scan, the point data can be linked to the RGB color data from the imagery leading to the points with XYZIRGB (X, Y, Z coordinates, return Intensity, and Red, Green, Blue color values) format. The positional error of any point in a point cloud is equal to the accumulation of the errors of the scanning control and errors in the individual point measurements. Point cloud data can be used either in Autodesk or in Bentley packages leading to a DWG or DGN deliverable. We describe here 2 case studies with DGN and CAD deliverable.

Case Studies

Bridge Survey

The first case study was using the static scanner on a bridge to assist field surveys. The scope of the work involved surveying approximately 160 feet in length (including the bridge) with a survey corridor of 200 feet either side of the existing centerline. The scope of work involved:

- Determining accurate elevations and locations of existing facilities, e.g., utilities, roadways, bridges, and culverts, for purposes of bridge design
- Creation of detailed planimetric and topographic surveys along the project corridors
- The planimetric and topographic files needed to be delivered to the client in MicroStation format

Prior to commencement of any static LiDAR acquisitions, the survey crew prepared and validated the ground control needed for the project. A Survey Control Network (SCN) was established to the appropriate state plane coordinate system (NAD83/2011, NAVD88). A total of eight control points were established for the scanning portion of this job in addition to the two control points established for the traditional field run survey.

Along with the control layout, plan for the scanning phase was also made. It involves identifying locations where the scanner is to be positioned. These locations were carefully selected based on access to the point, safety of the place, and that maximize the line of sight. The placement of scanner position is also important to avoid any shadows in the points. Scanning was performed using FARO Laser Scanner Focus 330, which enables fast, straightforward, and ultra-high accurate measurements of objects and buildings. A total of 11 scans were performed to get the complete coverage of the project site. The entire scanning was completed in eight hours including the setup time. Following field level data collection, captured data is transferred to our office system from SD card, where a display of the recorded data is immediately available for validation. A preliminary quality control (QC) check is performed to ensure full coverage of intended areas, and that the collection is good for further processing.

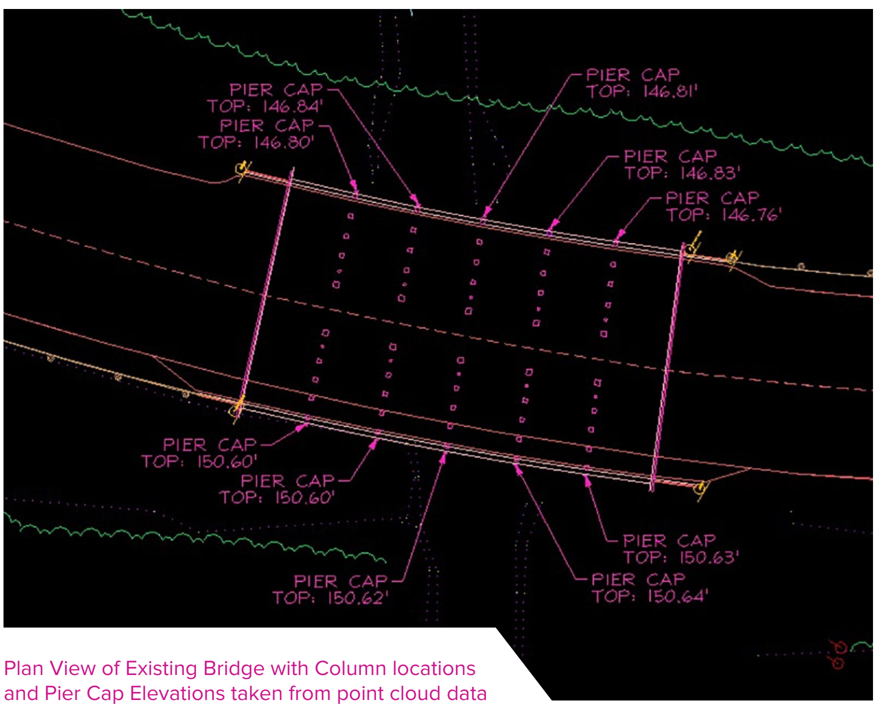
Faro Scene Software was used to perform the initial processing. The first step in the data processing was cloud to cloud registration. In registration, process, various 3D point cloud data are consistently aligned to result in a complete model. This is an iterative process until a good complete model is created. After the scans have been registered in logical clusters and locked, then the next step is georeferencing using the control points. During this stage, control points were identified in the scan project. The success of this step depends upon the number of points used, position deviation, and scan point drift.

After the project has been registered, a review will be performed on the error distribution between the point cloud and the control. If the error deviation is within the acceptable limit, the data will be exported to the target system for feature extraction and subsequent delivery. Since in this case the deliverables have to be in DGN format, TopoDOT was used for feature extraction. The data from Scene software was exported in POD format for use in MicroStation. The extraction of features and their attribution was performed in TopoDOT.

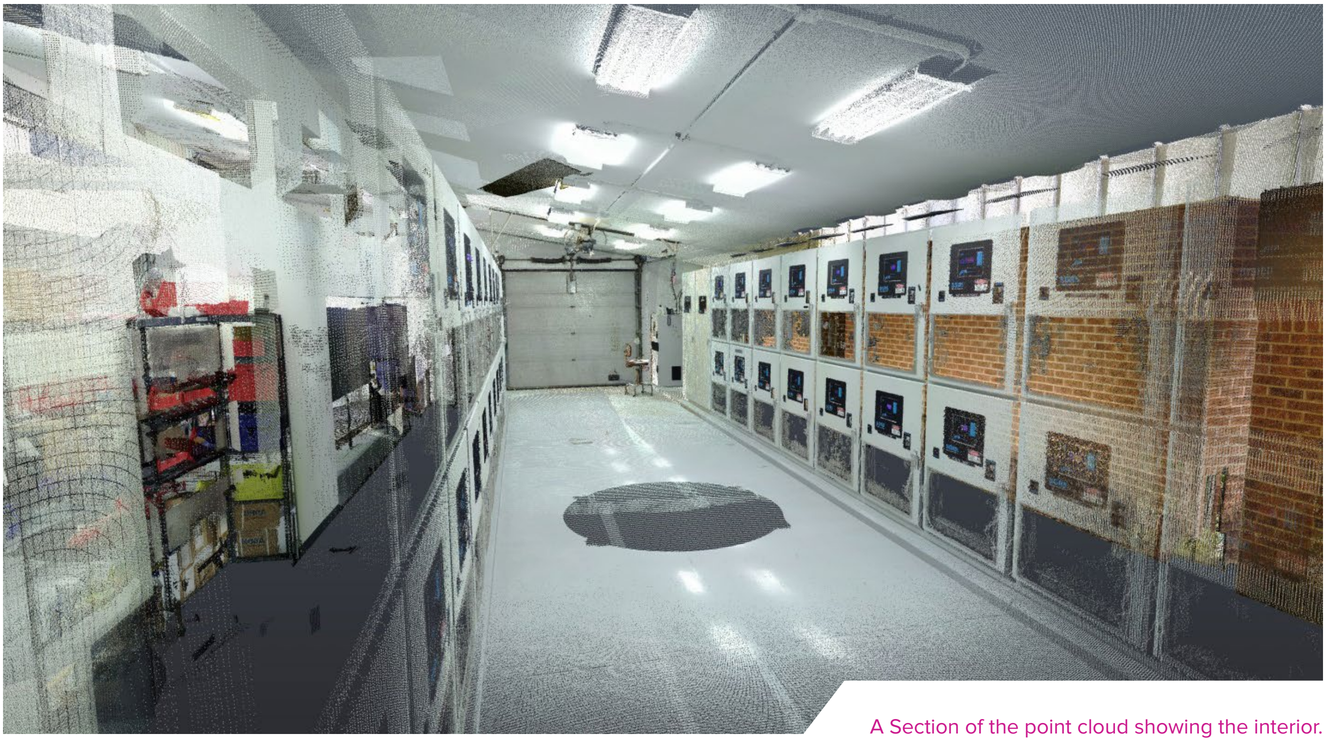
> "The placement of scanner position is to be carefully selected based on access to the point, safety and maximum line of sight."

Scanning the interior of a building

Very recently, we have performed a 3D laser scan and Building Information Model (BIM) for a client project. The Faro X330HD scanner was used to collect 16 interior and 12 exterior scans. The fieldwork took almost two days to complete. This included tying the project coordinates to client specified grid, as well as various measurement checks for Quality Assurance (QA) / Quality Control (QC) of the scanning process. The data was processed using the Faro Scene software using the steps given earlier. However, in this case the deliverable had to be in AutoCAD format. So after cloud to cloud registration and georeferencing were completed, the data was exported to Autodesk Recap to be used in Revit. Architectural and mechanical, electrical, and plumbing (MEP) elements were then modeled in Revit for the final



Plan View of Existing Bridge with Column locations and Pier Cap Elevations taken from point cloud data



A Section of the point cloud showing the interior.

deliverable. This particular BIM model took approximately 40 hours to produce.

QC Process

Before the data extraction, sufficient QC is been performed on the data by our technicians, who possess a surveying or equivalent technical background and are supervised by knowledgeable professionals trained in horizontal and vertical control techniques. Additionally, we observe the following practices:

- We maintain excellent geometry with target placement. This includes placing targets in varied directions and at varied elevations. Various target types may be used to obtain the desired results. Convention dictates that each scan should have a minimum of three inter-visible targets.
- Conventional survey equipment and procedures may be utilized to tie the scan(s) to the desired coordinate system and/or independent measurements may be performed by other methods to verify point cloud accuracy.
- An inspection of the registered point cloud and the registration report in comparison to the final deliverable (model) is always made to validate that the project specifications have been met.

Conclusion

It is clear from the two case studies that the static LiDAR adds value to the survey work in multiple ways. The two most obvious advantages are

- The ability to acquire data quickly with a richer data density and the precision of the data enables the job to be done efficiently.
- Flexibility to use the point cloud in different packages to meet the client's needs.

Dr. Srini Dharmapuri, CP, PMP, GISP is with MA Engineering Consultants (MAEC) in Dulles, VA as Director—Geospatial. Dr. Dharmapuri has Master of Science (Physics), Master of Technology (Remote Sensing), and Doctorate (Satellite Photogrammetry). Dr. Dharmapuri has over 30 years of extensive, wide-ranging experience within the Geospatial industry; most notably with LiDAR, Photogrammetry, and GIS. He has worked in both the private and public sectors, as well as internationally. In addition to his educational achievements, Dr. Dharmapuri is also an ASPRS Certified Photogrammetrist, Certified Mapping Scientist—LiDAR and licensed Photogrammetric Surveyor in South Carolina and Virginia, as well as a Certified GIS Professional and Project Management Professional. Dr. Dharmapuri is actively involved with ASPRS and ASPRS-EGLR.

Can Advancements in Mobile Lidar Combat the Trend for DIY Surveys?

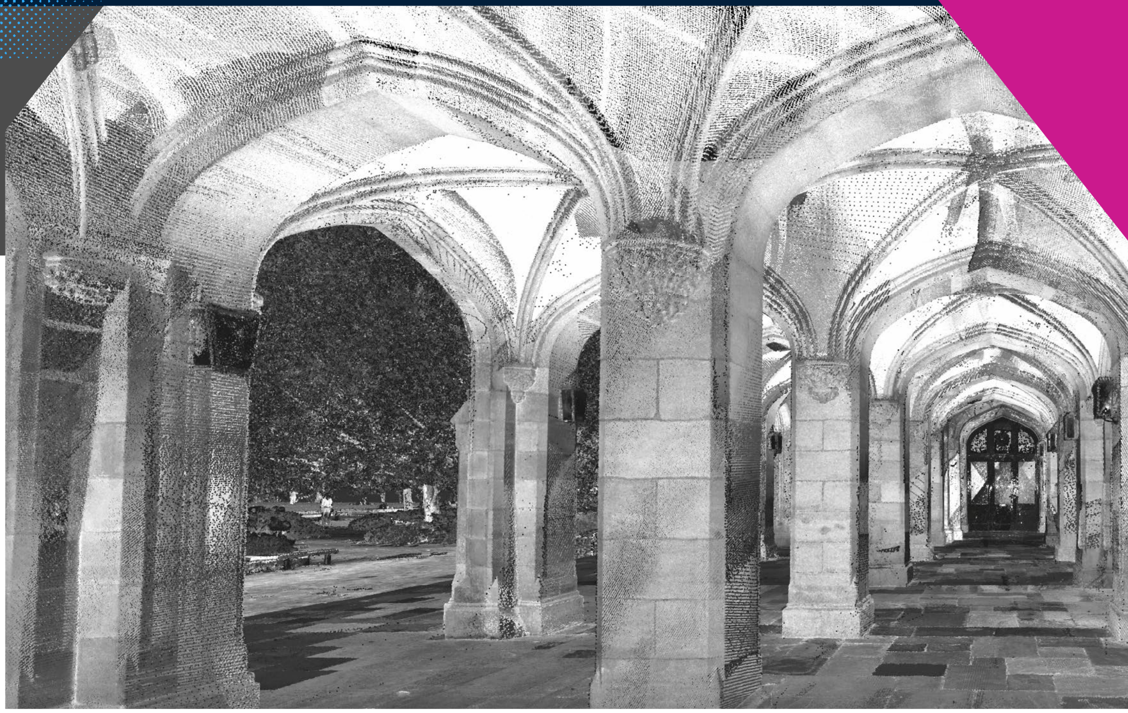
BY JOE BEECHING

The ROBIN Mobile mapping system being used in backpack set-up.

From smartphone apps for 3D mapping, to UAV photogrammetry, surveying technology just hit the mainstream. It's never been easier for individuals to inspect, measure and monitor their environment, so surveying businesses need to stay ahead of the curve if they are going to combat the wave of DIY equipment now available on the market. Mobile LiDAR systems are one such technology which stand to differentiate the experts from the amateurs when it comes to delivering the best service and data to the ever-growing number of paying clients, and here's why mobile LiDAR systems are having such a big impact.

In the early 1980s, LiDAR was itself a ground-breaking technology. As with drones, the technology was originally prohibitively expensive and reserved

Right: Point cloud of the Cloisters at Melbourne University, Australia. Data collected using ROBIN +PRECISION mobile mapping system.



Below: Colorized point cloud of the Sydney Olympic Stadium collected using ROBIN and the FLIR Ladybug5.

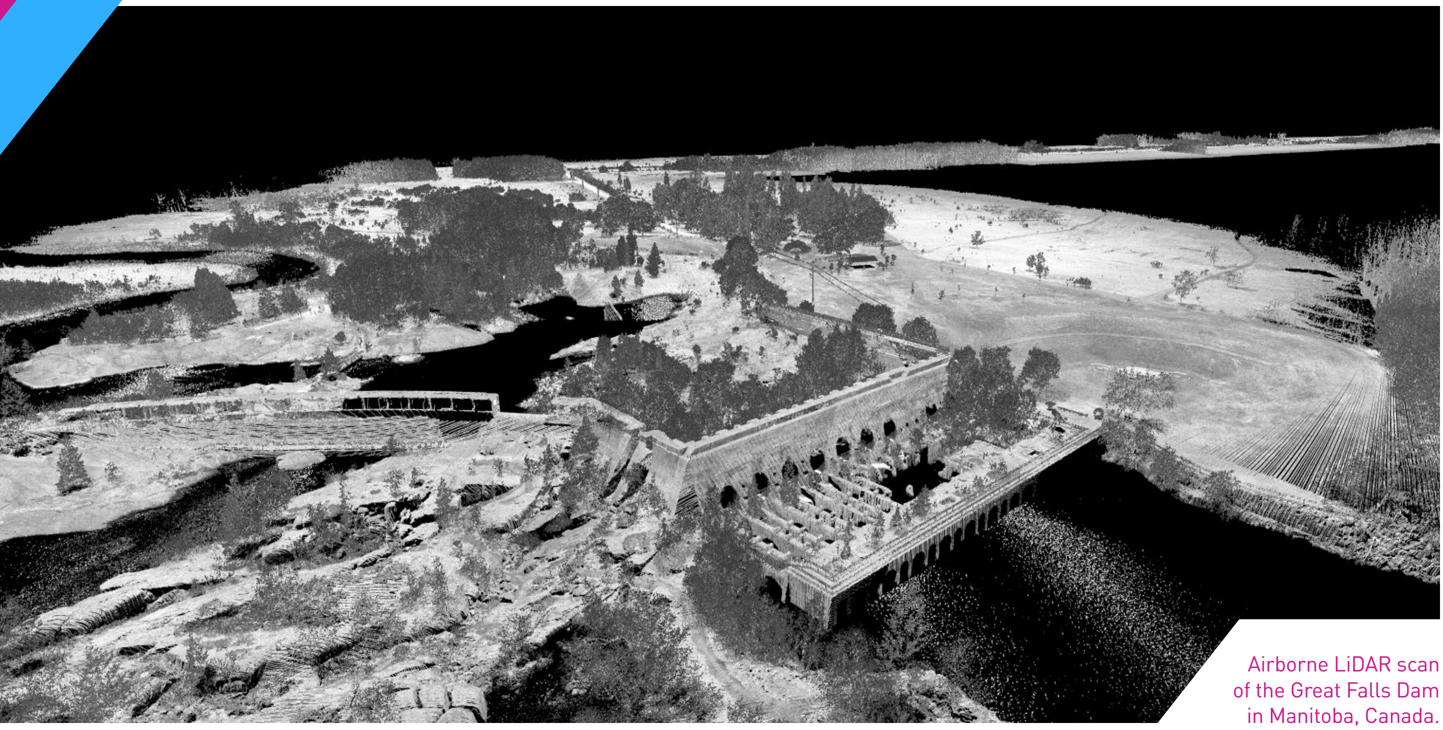
for military or scientific applications such as NASA's Apollo 15 mission in 1971. The first commercial LiDAR systems appeared on the market in the early 1990's with the technology rapidly evolving over the next two decades. Nowadays, LiDAR systems are used for hundreds of applications—from cave mapping to the navigation of autonomous vehicles.

LiDAR is similar to radar but uses a different part of the electromagnetic spectrum. Where radar uses micro or radio waves, LiDAR uses the beam from a laser to scan the object or environment, creating a collection of accurately measured points in seconds. Together, these points are known as a point cloud, which can contain trillions of measurements that can be accurate down to fractions of a millimetre.

Each point in a point cloud is precisely referenced with x, y and z co-ordinates relative to all other point locations. These coordinates are gathered from the integrated IMU (inertial measurement unit) which allow for positional accuracies to be established down to a sub-millimetre level, something which is impossible to achieve with photogrammetry or a smartphone.

Over the last decade there have been many discussions and articles written to evaluate the benefits of LiDAR over traditional topographic methods of surveying. Many of these focussed on the accuracies and time saving advantages of laser scanning versus conventional surveys, and despite the obvious cost implications, LiDAR is generally proven to be the more accurate and efficient tool for the job.

In reality, it is now the flexibility of LiDAR systems that really stands out when it comes to choosing a surveying method. Mobile laser scanning has become a game-changer for surveyors looking to provide services across a range of sectors. The ability to survey large areas, across almost any terrain



Airborne LiDAR scan of the Great Falls Dam in Manitoba, Canada.

means that surveying businesses can deliver results faster and in much greater detail that previously possible.

Amongst the first types of mobile laser scanners available were airborne systems. Since the mid-1990s, airborne laser scanning (ALS) has been used to generate detailed three-dimensional maps across large areas and, despite advancements in photogrammetric techniques and software, it remains the most accurate method of acquiring topographic data from the air.

One of the biggest drawbacks of airborne laser scanning has always been the cost involved. Whether commissioning a survey or buying the necessary equipment, the cost of ALS can be prohibitive for many surveying businesses or service users. This is one of the reasons that Unmanned Aerial Vehicles (UAVs), or drones, have started to see widespread use in the sector. Even low-cost UAV systems often have HD cameras capable of taking images at high enough resolutions for successful photogrammetric projects, yet limitations in battery life and payload capacity prevent most entry-level UAV systems from being truly fit for detailed surveying projects.

ALS systems have always held the advantage over photogrammetry thanks to their ability to scan through dense vegetation, making them ideal for surveys where assets and targets may be obstructed by trees. The latest ALS systems can now record the whole form of the returned signal, known as waveform, recording multiple echoes of each pulse. These multiple echoes allow the vertical profile of multiple objects to be measured within the laser footprint. It's this capability that has also seen airborne LiDAR become one of the most accurate methods of mapping forest structures and carbon stocks.

Mapping and modelling using ALS may be expensive yet the point cloud density, speed of capture and accuracy of data is unparalleled—until you combine it with data collected from the ground. Vehicle mounted LiDAR systems have been around for a few years and have allowed highway and rail operators to map their networks and assets while on the move, meaning that there is less disruption to service users. This, coupled with the lowered risk of collecting data remotely, has led to this type of system being adopted by many local governmental organisations and contractors across the globe.

Combining airborne data with data collected from the ground allows for even more detailed survey results. Once the two datasets are combined, a denser point cloud can be generated, with relative accuracies of as little as 3mm. Obviously, this method of surveying requires the possession of both an ALS system and vehicle or backpack mounted system for the ground level survey, something which requires significant investment or collaboration with other teams.

Building a Business Case for MLS

Systems such as ROBIN represent a further step-change in the use of LiDAR for surveying tasks. Multi-use mobile mapping systems take the scope for laser scanning further by offering the ability to mount the LiDAR system in different ways. One of the reasons that many surveyors rely on traditional methods and technology, such as GPS and total stations, is the lack of budget or ability to invest in such an expensive capital purchase.

Justifying or raising investment for a large capital purchase can often be difficult, especially when it comes to investing in new technology. This is why many companies are now exploring cheaper surveying solutions. As many surveying businesses have invested in terrestrial laser scanners in recent years, it also becomes more difficult to substantiate reinvestment just because the technology has advanced.

Multi-platform mapping systems allow for enhanced services to be offered by one company. In the case of ROBIN, you can attach the same system to a backpack, vehicle or helicopter and swap between each function in a simple transition. This means that building a business case for a mobile mapping system is easier to justify. Often, surveying teams will specialise in either ground level or airborne data capture, not usually both. These flexible systems make it easier to diversify a service offering to cover both ground and air projects, even where detailed data is required or access to the site is limited.

UAV LiDAR

Standard UAVs have become a great way of dipping a toe in the water of the latest disruptive technologies and are often a good enough platform for entry level surveying tasks where accurate geopositioned measurements are not required. Roof inspections and even infrastructure surveys can be carried out by a single drone operator quickly and safely, they simply cannot provide the levels of detail contained within a point cloud.

It's only been in recent months that UAV LiDAR systems have become an affordable possibility for many commercial operations. The limitations of payload weight on a standard UAV has meant that integrating an IMU and laser scanner was an impossible feat; other than for heavy-lift systems, which in themselves are prohibitively expensive for most surveyors. Thanks to further advancements in MLS technology, scanners can now be small and compact enough to fit on a UAV system without having to be a gamble.

ROBIN mini is one of a few systems available which combines the affordability and ease of a drone survey with the detail and accuracy of LiDAR. The lightweight laser scanner has been designed specifically for use with a UAV and makes use of the same echo signal digitization and online waveform processing technology which made ALS so popular for mapping dense vegetation.

Although flight time will still be limited without a tether, these compact and lightweight UAV LiDAR systems can collect around 100,000 measurements per second, making light work of construction and building surveys, powerline inspections and infrastructure projects.

These types of system now prove that LiDAR can be an affordable alternative for surveying businesses either looking to diversify their offering or looking to utilise the latest in disruptive technology without compromising on data quality or accuracy.

It's always been easier to justify the introduction of entry level technology and we are now in an era where technology moves at a speed where it can be easier to ignore advancements or to choose a cheaper option until a proof of concept has been established. UAV LiDAR and mobile mapping systems are now at the stage where it is not only commercially viable, but also affordable for most commercial surveying operations. Yes, a smartphone could map the inside of your house to help you measure for a carpet, but can it really be relied upon to provide the accurate data a client needs to make critical decisions? Will a drone equipped just with a 20MP camera be able to provide a dense and accurate enough point cloud to enable clients to plan major highway expansions or smart city initiatives? Probably not.

Technological advancements are what keep us striving to find new solutions to old problems and it'll be a while until your average smartphone or tablet can integrate a LiDAR sensor. ■

Joe Beeching, LiDAR Systems Engineer, 3D Laser Mapping, has worked in the GIS and surveying industries since 2004, and has been working with LiDAR technologies since 2005. His background is in Earth Sciences, graduating from Brunel University in 2003 with a First Class (Hons) Bachelor's degree. Joe joined 3D Laser Mapping Ltd in 2005 and provides technical support for laser scanner hardware and software.

Graham, *continued from page 48*
geopositioning system. The X4s is a fixed magnification lens with a hybrid shutter that provides a mechanical leaf exposure below a specific exposure time. For our direct geopositioning test, we used fixed camera calibration that we had conducted in our lab. This demonstration was really aimed at how well our Loki direct geopositioning system could perform using no ground control but, of course, the system can do no better than the camera will allow! The overall goal was to generate 1' contours.

We set out 18 ceramic tile photogrammetric targets (see **Figure 1**) over this 175 acre limestone mine site, surveying them in using RTK with a local base station. Our base station was positioned using the National Geodetic Survey's Online Positioning User Service (OPUS) thus this represents the network tie in the following discussion.

The overall accuracy of the resultant 3D point cloud (as produced in PhotoScan Pro) was a root mean square error (RMSE) of 0.11 feet (3.36 cm). This is with *no* ground control! Obviously we are well within the accuracy requirement for 1' contours. As an additional check, we compared our survey in undisturbed areas to contours that had been derived from a high accuracy LIDAR scan performed some months before. This conformance test was performed by extracting points along a road surface (see **Figure 2**) from the LIDAR-derived contour data and using these points as *test points* in the current drone-derived point cloud. This test yielded an RMSE of 0.13 feet (4.0 cm). You have to admit that these are remarkable results. We would have been very happy to see this with a 1.5 million dollar DMC back in the day!

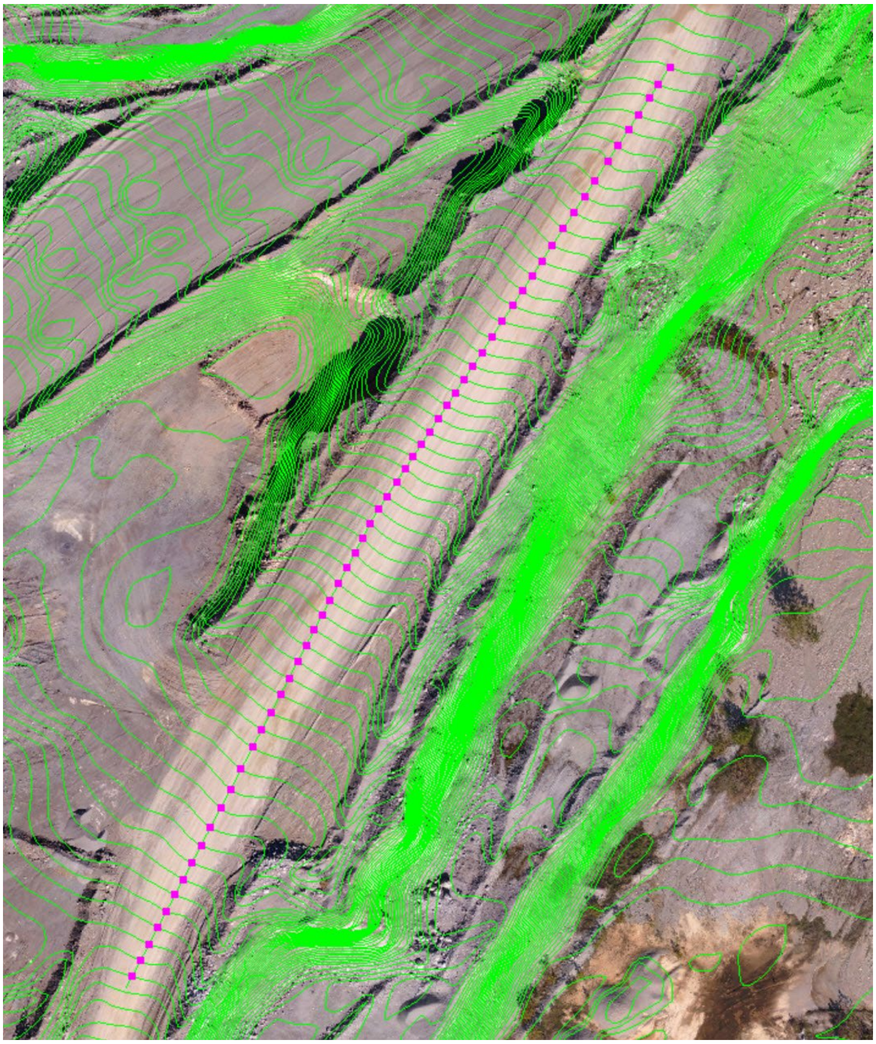


Figure 2: Conformance test points derived from LIDAR

So the proof is in the pudding, not in pontificating about the pudding. With very careful procedures and attention to detail, you can fairly easily achieve accuracy with a very low cost drone system comparable to a very high end photogrammetric mapping camera. Of course, a drone is very seldom a replacement for a manned aerial survey (due to the postage stamp project areas that are practical with drones). Thus my advice is that everyone who currently has a manned photogrammetric mapping practice should examine where or if drones will fit in their business model rather than perceiving the technology as a threat to their current practices.

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.

Yes, Virginia, you can *accurately* map with a drone!

Wow, can you believe it is 2018? I completely lost 2017! Anyway, the best of success in the New Year!

I read article after article by employees and owners of traditional LIDAR and photogrammetric mapping firms who say, due to some sort of mystical physics, it is impossible to achieve accurate mapping with a low cost drone/camera using dense image matching. In this article, I hope to dissuade you from accepting these patently false claims.

Our AirGon subsidiary specializes in creating hardware and software for high accuracy drone mapping. We do a lot of flights for testing equipment, proving accuracy to customers, demonstration flights and so forth. To date, we have conducted over 1,000 metric mapping drone flights with high end systems (both fixed wing and rotary wing), the SenseFly eBee and just about every DJI drone made. By a metric mapping drone flight, I mean we have specifically targeted the project site for the purpose of quantifying accuracy. All flights are conducted with on-board direct geopositioning; for DJI equipment, we use our own Loki system. For the eBee, we use the RTK version. Interestingly, both SenseFly and us use a GNSS engine from Septentrio.

A bit of background. We know quite a bit about metric mapping cameras. Prior to GeoCue/AirGon I and my core team were at Z/I Imaging. Part of my job in running Z/I Imaging was overseeing the development of the Digital Mapping Camera (DMC). This was the world's first large format framing metric mapping camera. We learned a lot about both building and testing camera systems!

Of course the focus of a good drone mapping system should be primarily aimed at the sensor. As long as the drone can carry the sensor over the mapping area according to a flight plan and not bounce all over the place, it is not going to contribute in any significant way to the quality of the mapping

I ask a lot of persons to define for me a metric camera. I get a variety of vague answers about this but the most typical definition is that it is the camera in their airplane! Actually, the notion of a metric camera dates to the days when mappers had to work directly from film with mechanical stereo plotters. Distorting aspects of a camera such as radial lens distortion could not be modeled in these exploitation systems so very expensive, distortion free lenses had to be manufactured (we continued this tradition with the lenses of the DMC, even though it was not necessary). There are probably two major properties of a camera that are necessary for accurate mapping in this age of digital data correction—a reasonable modulation transfer function (MTF) and *stability*. MTF describes how well the optical system responds to spatial frequencies (in film cameras, we used to talk about

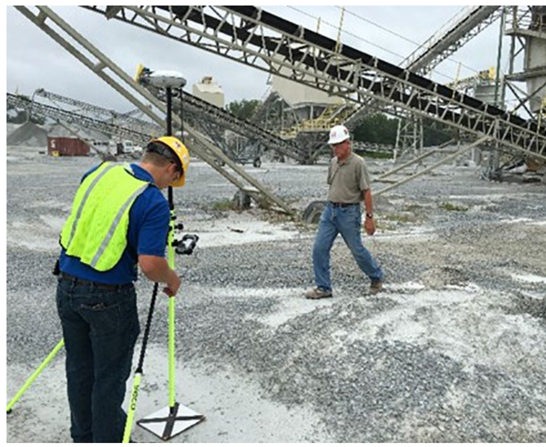


Figure 1: A ceramic tile photogrammetric target

line pairs per millimeter). The stability of a camera refers to how much the modeling parameters (such as focal length) vary from project to project or even from shot to shot. These days even a truly terrible lens can be modeled but only if it is not changing in an erratic way from project to project.

Camera manufacturing processes and the material used have become so good that even a sub $500 camera can provide adequate performance for metric mapping. The main factors these days that introduce errors that are difficult to model include rolling shutters (just don't try to map with this type camera—they are for video) and zoom lenses.

In a recent mine site mapping project, we did a fairly extensive test using a DJI Inspire 2 with a DJI X4s camera and our AirGon Loki direct

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