LIDAR MAGAZINE

VOLUME 11 ISSUE 5

WINTER 2022

SPECIAL ISSUE

AIRBORNE SHOWCASE

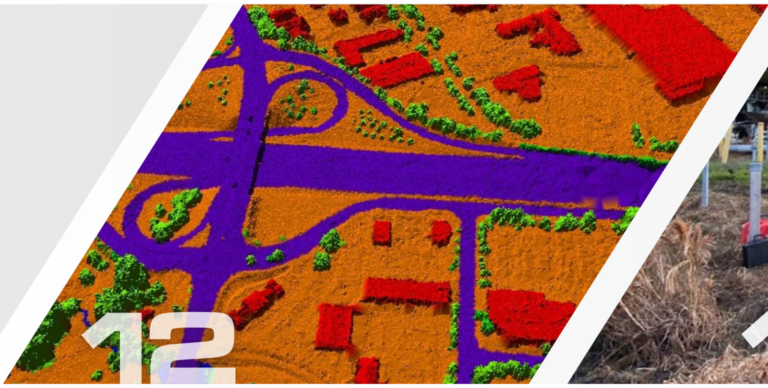
6 NEXT GENERATION TOPO-BATHY
How high can you fly and still collect lidar bathymetry? Woolpert's R&D lab answers

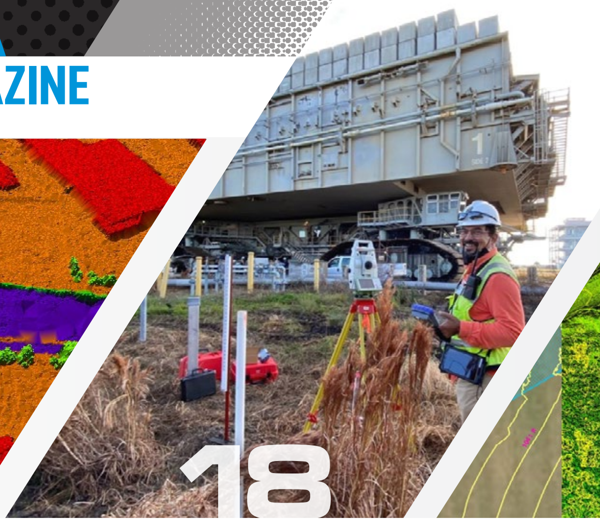
12 UAV PROJECT PARTNERS
Bay Area startup GeoWing Mapping prospers with UAV-photogrammetry

18 REAL-TIME SURVEY FOR NASA
Preparing for the Artemis I mission presented a unique survey challenge—moving objects

38 THE ESSENTIALS OF SAR
Editor Walker reviews a conceptual view of Synthetic Aperture Radar and its capabilities

LIDAR MAGAZINE





IN THIS ISSUE

6 Next Generation Topo-Bathy

What do you do when you need a specific technology that doesn't yet exist? You build it. The project to build the Bathymetric Unmanned Littoral LiDar for Operational GEOINT (BULLDOG) sensor started when Woolpert was asked a basic tactical question: how high can you fly and still collect lidar bathymetry? Woolpert's R&D lab set out to answer the question.

BY NATHAN HOPPER AND MIKE HARPER

12 GeoWing Mapping Prospers with UAV Photogrammetry

On a recent visit to several Bay Area lidar players, I was privileged to meet up with Rebecca A. (Becky) Morton, co-founder and CEO of GeoWing Mapping Inc., a small company offering UAV-photogrammetry and lidar services. GeoWing is based in Richmond, California. I was interested in the company's approach to lidar data acquisition and processing.

BY STEWART A. WALKER

18 Real-Time Surveying to Support NASA Launch

NASA plans to launch the Orion spacecraft on a 26-day mission around the moon via the Space Launch System, its new heavy-lift rocket, in late 2021. The unmanned Artemis I flight is the first in a line of complex missions aimed at enabling exploration of the Moon and Mars. First, it must make it to the launchpad.

BY BRIAN MERRITT AND GARY MCDANIEL

24 A New Hybrid Product Approach

Continuously declining construction project funding poses a great challenge for agencies attempting to finance new projects and/or maintain existing ones. With constrained budgets, many agencies struggle to meet their development objectives and are searching for creative ways to advance their projects. Recognizing clients' need for survivability and resilience, Woolpert researched creative methods for enabling goal achievement under strict budgets.

BY QASSIM ABDULLAH AND TOM RUSCHKEWICZ

34 Cloud Native Geospatial Lidar

Most point-cloud processing tasks do not require all the data, but commonly used lidar formats require programs to read it all—whether over a network or directly from disk. In the case of compressed formats such as the LAZ format, reading it all means extra effort to decompress everything too.

BY HOWARD BUTLER

42 DeepRoute on the Road to Making All Transportation Autonomous

Since LIDAR Magazine spoke with DeepRoute in July, the company has deployed robotaxis in Wuhan and Shenzhen, and received a Drivered Autonomous Vehicle permit from the California Public Utilities Commission. After receiving an award last year for its unique combination of software and sensing solutions, the company showcased its DeepRoute- Engine at CES 2021.

BY VICTOR WONG

COLUMNS

2 ***From the Editor:***
Mixed feelings at year's end
BY DR. A. STEWART WALKER

38 ***Book Review:***
The Essentials of SAR
BY DR. A. STEWART WALKER

DEPARTMENTS

48 ***In Memoriam:***
Martin Isenburg: 1972-2021
BY HOWARD BUTLER

◀ ON THE COVER

Topo-bathymetric lidar data from coastal Florida, courtesy of Woolpert.

LIDAR To Go!
Get the most from this magazine on your tablet or laptop.

QUICK-FIND: Our digital edition offers searchability, hotlinks, video and more. The search-glass icon or find bar is accessible on any tablet or computer.

DR. A. STEWART WALKER

Mixed feelings at year's end

Lidar shines despite global turbulence

We couldn't hide disappointment as 2021 drew to a close. US politics are deadlocked. Travel remains risky and limited. There is uncertainty, indeed volatility in several areas of the world. Things can only improve—or is there scope for worsening?

The conference scene has been severely compromised by the pandemic. People's longing to meet face-to-face, however, ensured that 2021 saw some very successful events, particularly the Commercial UAV Expo, held by Diversified Communications in September in sweltering Las Vegas. There were many excellent online events, for example those run by ISPRS and ASPRS, the latter both national and regional. Some events were hybrid, such as the Fall Lidar Workshop run by the ASPRS Florida Region and the University of Florida, hosted in the hangar of GPI Geospatial, Inc. in Orlando—generous social distancing in a space designed for aircraft! We long for face-to-face events in 2022 and have already listed some[1]. Preparations are advanced for Geo Week in Denver in February, which will be a fine conference and we will include the presentation of the Lidar Leader Awards, for which once again we have received a large number of excellent nominations. The French organizers of the XXIVth ISPRS Congress, now scheduled for June 2022 in Nice, France, provided two online events to compensate for the postponements of the live event in 2020 and 2021. We exhort readers to attend and firms to exhibit, to ensure that the Congress is successful, the extra costs borne by the organizers are recouped and we all learn as much as we can from this exquisitely organized feast of photogrammetric and remote sensing research, amongst which lidar plays a lively role.

This issue is an important one. We have reported on the tragic death of lidar guru and personality Dr. Martin Isenburg. Here we offer an obituary penned by Howard Butler, who also contributes an article on his firm's Cloud Optimized Point Cloud specification, which augments Martin's renowned LAZ format.

We have an extraordinary article by the engineering and environmental consulting firm Langan, derived from a presentation given at the Lidar Workshop run jointly by the ASPRS Florida Region and the University of Florida, which took place remotely on 21 June 2021[2]. This describes the surveying of an enormous transporter to move

1 https://lidarmag.com/2021/11/15/back-on-the-road/
2 Karlin, A., 2021. Energetic data acquisition in Florida, *LIDAR Magazine*, 11(4): 40-45, Oct-Nov 2021.

LIDAR MAGAZINE

www.lidarmag.com

2021 Vol. 11 No. 5

PUBLISHER Allen E. Cheves
publisher@spatialmedia.us

MANAGING EDITOR Dr. A. Stewart Walker
stewart.walker@lidarmag.com

ASSOCIATE EDITOR Jeff Winke
jeff.winke@lidarmag.com

EDITOR EMERITUS Marc S. Cheves, LS
marc.cheves@spatialmedia.us

CONTRIBUTING WRITERS
Dr. Qassim Abdullah
Dr. Srini Dharmapuri
Jeff Fagerman
Dr. Juan Fernandez-Diaz
Lewis Graham
Dr. Al Karlin
Aaron Lawrence
Raymond Mandli
Dr. David Maune
Mike Shillenn
Evon Silvia
Ken Smerz
Dr. Jason Stoker
Larry Trojak
James Wilder Young
Dr. Michael Zanettii

The staff and contributing writers may be reached via the online message center at our website.

GRAPHIC DESIGN LTD Creative, LLC
WEBMASTER Joel Cheves
AUDIENCE DEVELOPMENT Edward Duff

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

Made in the United States of America

SPATIAL MEDIA

OFFICIAL PUBLICATION
USIBD U.S. Institute of BUILDING DOCUMENTATION

NASA's Orion spacecraft from assembly to the launch pad, a journey of 4.1 miles at Kennedy Space Center, for the Artemis I mission, currently scheduled for March 2022. The weight of the transporter and payload is an astonishing 12,500 tons, so the track they follow is likely to be affected—that's the crux of the surveying challenge!

Equally remarkable, we learn about an extraordinary topobathymetric sensor from Woolpert—we didn't know until recently that this company makes sensors, though it has been involved in sensor development for quite some time—that can fly higher than the existing sensors of this type, resulting in broader coverage, fewer flight lines and savings in mission cost and time. The science and engineering behind this sensor are truly impressive. Since receiving the article, *LIDAR Magazine* has visited Woolpert's maritime lab in Bay St. Louis, Mississippi to see the sensor at first hand and learn more about the technology and the team involved—the report is in preparation.

LIDAR Magazine has covered the vibrant lidar activity in the automotive world, where the demands of the vehicle manufacturers coupled with the sprouting of numerous energetic, innovative start-ups, spurred in many cases by SPAC financing models, has caused the cost of sensors to plummet. Some of these are barely good enough for geospatial work, but others are just fine. Not only their cost, but also their weight and power requirements, have transformed the UAV-lidar world. On vehicles, the ADAS applications are universally welcome—we all enjoy gadgets that keep us in lane, help us park and stop us from hitting the car in front—but AVs still encounter a mixed reception; reports of failures, injuries and deaths are carrion to the naysayers. The article by DeepRoute, the second time we have featured this company, is focused on robotaxi applications in China, undergirded by testing on a massive scale, and is compelling. Progress is being made—enjoy your stickshift while you can!

Qassim Abdullah (also Woolpert) and Tom Ruschkewicz provide invaluable advice as they describe how Woolpert fuses datasets of different provenance and accuracy into products that meet the requirements of transportation projects. Behind this is commonsense "horses for courses", to which are applied rigorous adherence to specifications and appropriate merge technologies. The economic implications are considerable, because existing data, often in the public domain, can be re-used, saving costs while meeting specifications.

Many of us have entertained dreams of founding our own geospatial companies. Some readers have done it. The story of GeoWing Mapping is a heart-warming one, following industry veterans Becky Morton and Alan Mikuni to success with photogrammetry and lidar after six years of hard work. GeoWing's business model is intriguing as it combines in-house UAV-photogrammetry with subcontracted lidar data acquisition, followed by in-house processing. We wonder if this will change as the system cost of UAV-lidar falls…

The issue concludes with a book review. Tom Ager retired after decades with the National Geospatial-Intelligence Agency and drew upon his accumulated expertise and experience of explaining to others the intricacies of synthetic aperture radar, to write *The Essentials of SAR*, comfortably accessible to those without strong backgrounds in physics and math.

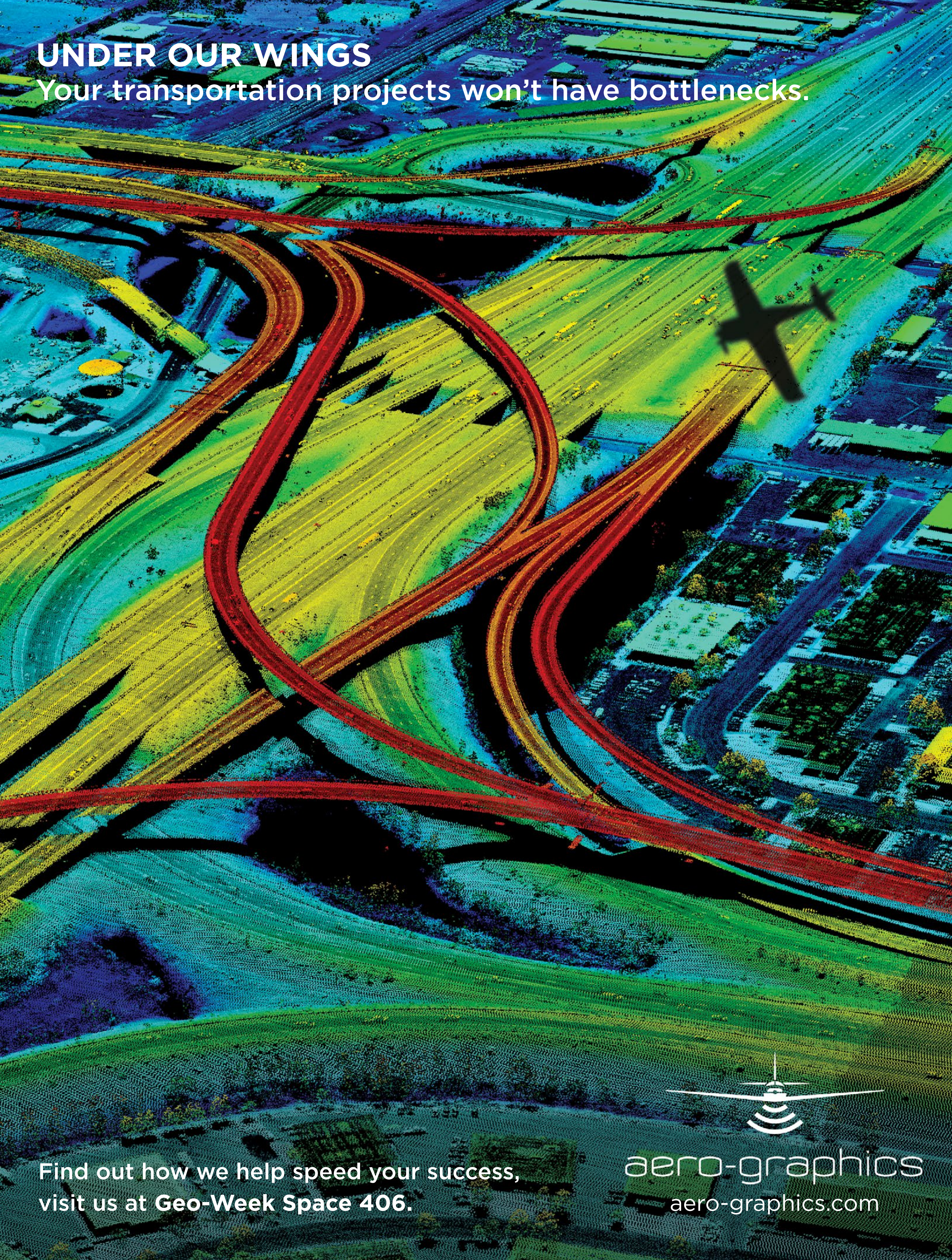
As is our wont, we end with nuggets from journals, half a century apart. We came across a piece about the use of the time-of-flight of pulses of ruby lasers to measure the positions of satellites from Earth in *Jena Review*, the scientific-technical journal of Carl Zeiss Jena in East Germany[3]. These were early days for lidar and the results were remarkable—remember that this was done 50 years ago. Returning to the present day, we spotted a release from Southern California Gas that it has signed a deal with Bridger Photonics, Bozeman, Montana, "to detect, pinpoint and quantify methane emissions thoughout [its] distribution area"[4] What a wonderful world!

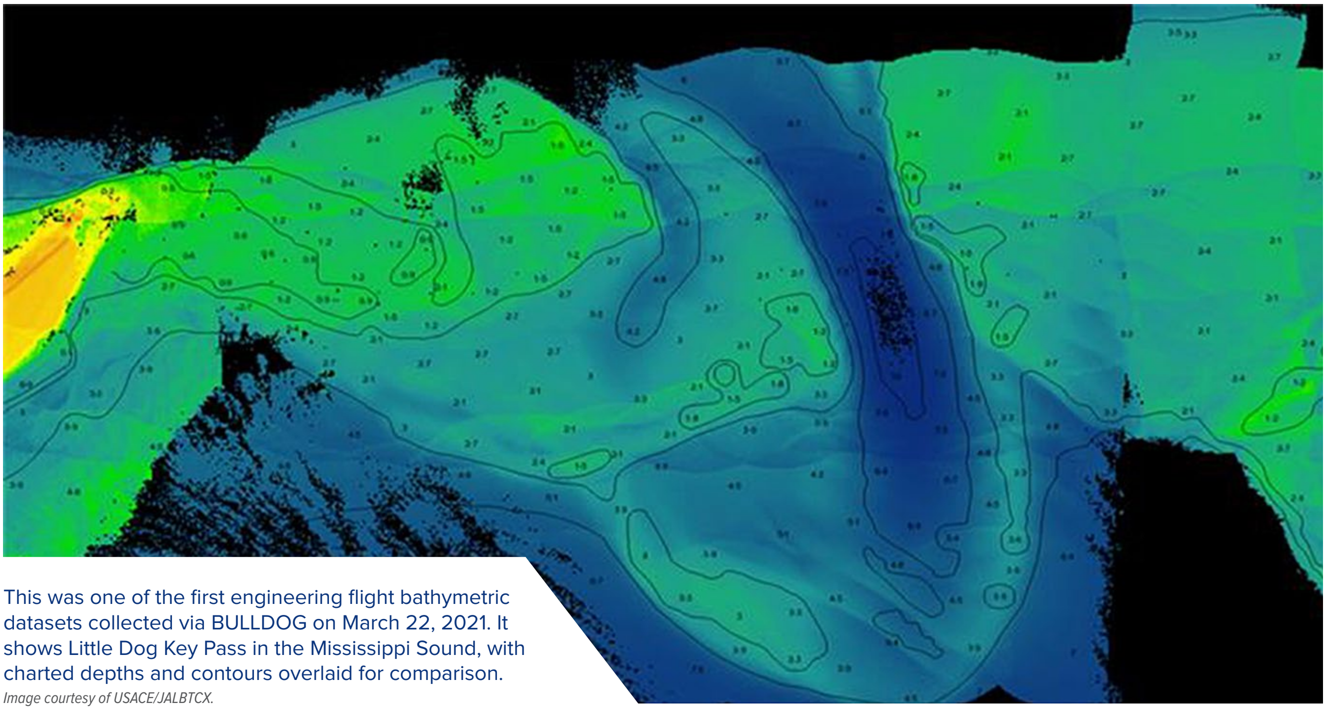
Thus we should end a tough year, where the daily news offers little respite, by reflecting on the positive. It's clear that the sensing technologies at the center of this magazine's world are rapidly developing and improving our world in multiple ways. Moreover, the community surrounding them—developers, suppliers, users—is lively and anxious to meet to exchange views and cement friendships. *LIDAR Magazine* looks forward to 2022 and wishes its readers well in their endeavors.

A. Stewart Walker // Managing Editor

3 Steinbach, M. and R. Neubert, 1972. Measuring the positions of satellites with the aid of laser pulses, *Jena Review*, 1972/7: 331-336.

4 Anon, 2021. Gas mapping lidar quantifies methane emissions, *Photonics Spectra*, (55)11: 20, November 2021.


UNDER OUR WINGS
Your transportation projects won't have bottlenecks.
Find out how we help speed your success,
visit us at Geo-Week Space 406.
aero-graphics
aero-graphics.com



This was one of the first engineering flight bathymetric datasets collected via BULLDOG on March 22, 2021. It shows Little Dog Key Pass in the Mississippi Sound, with charted depths and contours overlaid for comparison.
Image courtesy of USACE/JALBTCX.

Next Generation Topo-Bathy Sensor

Woolpert takes next step in lidar capabilities

What do you do when you need a specific technology that doesn't yet exist? You build it.

The project to build the Bathymetric Unmanned Littoral LiDar for Operational GEOINT (BULLDOG) sensor started when Woolpert was asked a basic tactical question: how high can you fly and still collect lidar bathymetry?

To answer this, Woolpert, a geospatial firm more known for its lidar data collections than its sensor development, established a research and development lab in Mississippi and assembled a team of experts from a wide variety of disciplines—from physicists and computer scientists to mechanical and electrical systems engineers. The team worked through initial designs, lab experimentation and field trials; navigated engineering and integration challenges; and conducted test flights throughout 2019, 2020 and early 2021. The result was a topographic and bathymetric lidar sensor that would fly higher with a broader swath and could collect data faster than other currently operating topobathymetric lidar systems.

BY NATHAN **HOPPER** AND MIKE **HARPER**

CZMIL SUPERNOVA

CZMIL SuperNova comes equipped with the most powerful green laser on the market. When in use, it's powerful green flash is legendary.

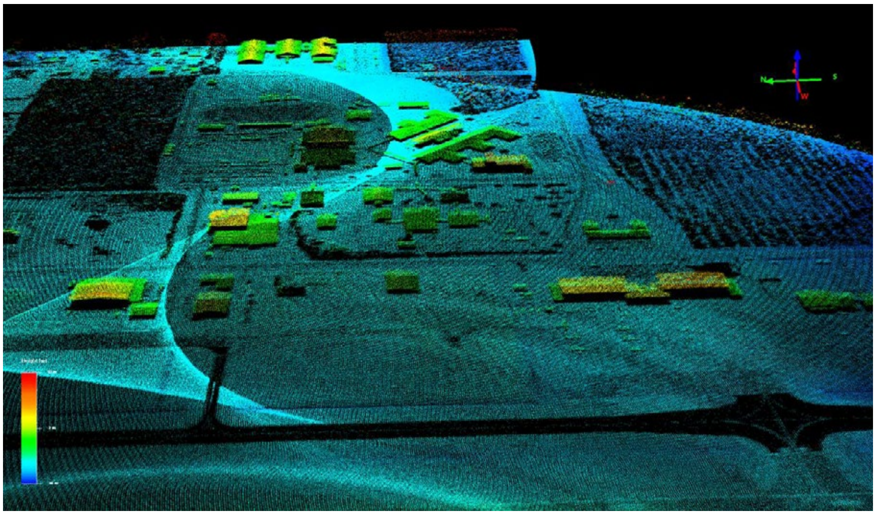
CZMIL SuperNova has the best penetration in turbid waters with exceptional performance in coral reefs, inland waterways, beaches and deep water marine. A complete geospatial solution, SuperNova is powered by CARIS processing and sensor fusion software.

FOR MORE INFORMATION:
www.teledyneoptech.com/czmil-supernova

TELEDYNE

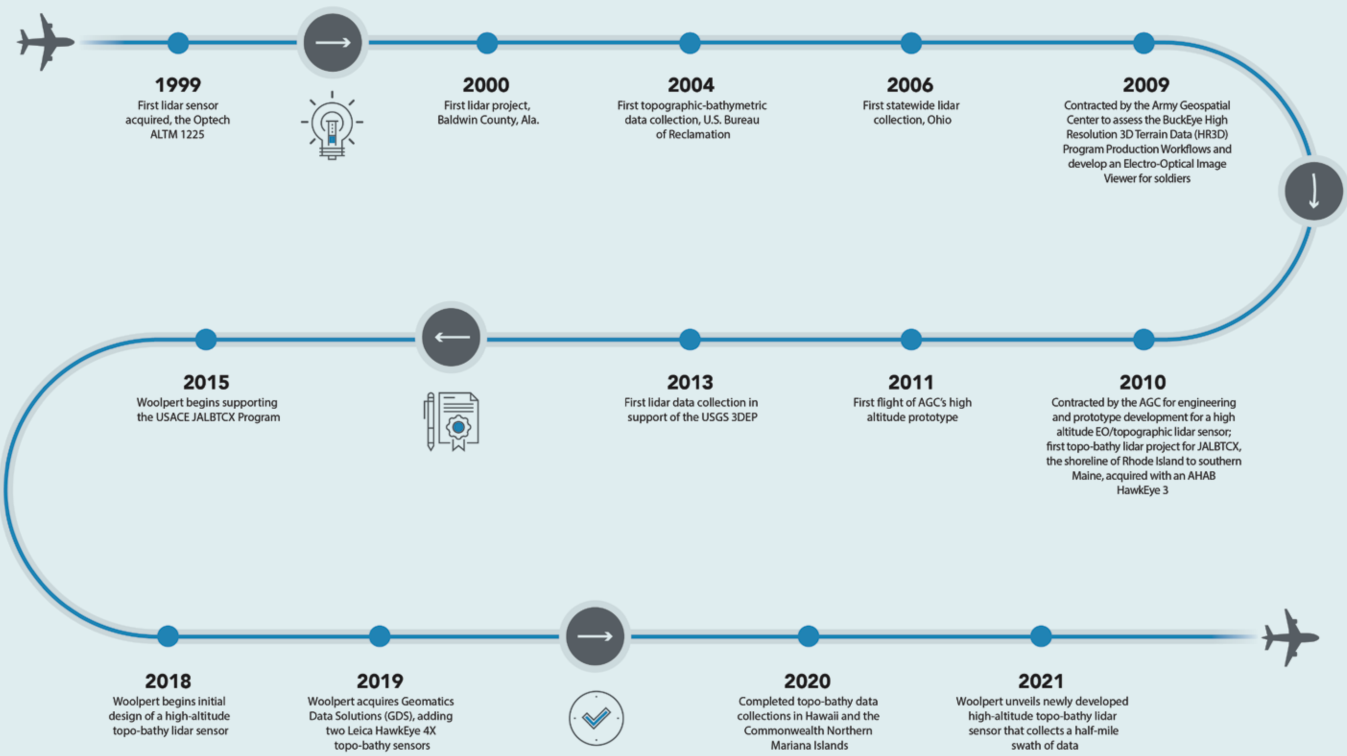
"Currently, with the bathymetric lidar sensors that are on the market today, to survey and map a coastline, you have to fly multiple parallel flight lines to get complete coverage of the coast," Woolpert Vice President Mark Smits said. "What we want to bring to the table is to be able to fly a coastline and get a good characterization of it in a single pass. So, with a broader swath and flying at higher altitudes, we can potentially map out coastlines faster, more efficiently and more safely due to the heightened elevation over challenging terrain. There is no other system like this on the market, because to do that is extremely challenging."

Jennifer M. Wozencraft is the director of the Joint Airborne Lidar



This topographic point cloud was generated with BULLDOG's Geiger-mode avalanche photodiode (GmAPD) sensor from an elevation of 10,000 feet over Stennis International Airport in Kiln, Mississippi. The GmAPD sensor is a multi-pixel array (32x128) capable of precise single-photon time-of-flight detection.

Image courtesy of USACE/JALBTCX.



Notable moments in Woolpert's lidar history.

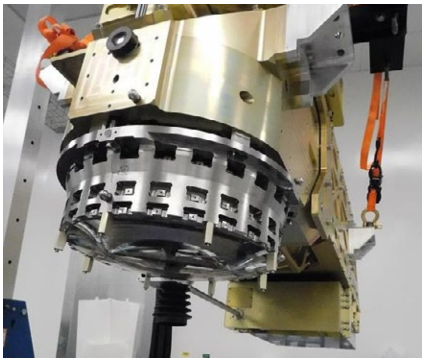
Graphic courtesy of Woolpert.

Bathymetry Technical Center of Expertise (JALBTCX), which contracted with Woolpert for BULLDOG. Wozencraft said that flying at higher altitudes and collecting topographic and bathymetric lidar data simultaneously will help address the increasing need for topobathymetric data around the world. JALBTCX performs operations, research, and development in airborne lidar bathymetry and complementary airborne coastal mapping technologies to support the U.S. Army Corps of Engineers (USACE), the U.S. Naval Meteorology and Oceanography Command, the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS).

"The higher a topo-bathy lidar sensor can fly while collecting accurate data, the faster information can be collected to meet requirements for coastal engineering, science and nautical charting," Wozencraft said. "This data helps our agencies maintain the coastal marine transportation system, prepare for, mitigate the effects of, and respond to short-term hazards like natural disasters and long-term processes like climate change, and conserve and restore the coastal environment. And this need will only continue to grow."

The long runway

Woolpert was founded as an engineering and survey firm in 1911 and began providing geospatial services in 1969. In 1999, Woolpert acquired its first lidar sensor and used it to complete the first countywide topographic lidar data collection in Baldwin County, Alabama, in 2000. This set the stage for the firm's innovative work with lidar. Woolpert conducted the world's first riverine topobathymetric lidar collection in Washington state in 2004 and followed by developing and carrying out



Woolpert's engineering prototype sensor incorporates both civil and military requirements.
Graphic courtesy of Woolpert.

the first statewide lidar program of its kind in Ohio in 2006. In 2015, Woolpert was contracted to test new single-photon and Geiger-mode lidar technologies for USGS.

Also, from 2009–2013, Woolpert collaborated with the U.S. Army Geospatial Center (AGC) to support its evolving High-Resolution Three-Dimensional Terrain Data (HR3D) program. AGC's BuckEye system, consisting of an airborne topographic lidar sensor and an electro-optical mapping camera, was created out of a warfighter necessity for high-resolution terrain data and imagery over urban and complex terrain in Iraq and Afghanistan. Woolpert provided early technical support to improve the system's data processing and helped create an imagery viewer to enable soldiers to quickly access individual frames.

As the need for imagery and improved elevation data exponentially grew and extended beyond Iraq and Afghanistan, so did the need to collect the data more efficiently. This spurred the development of a system that could fly higher and collect data over a much larger area, while still maintaining the high resolution and accuracy of the current systems. This led to the development of the BuckEye 2 sensor.

Woolpert led the design, integration, and testing of BuckEye 2 and developed the initial data workflow and processing to satisfy the warfighter's higher altitude and collection requirements. Woolpert and its mission partners successfully transitioned the sensor to AGC, immediately putting the system into operational use.

Since then, Woolpert has continually expanded its geospatial expertise and resources through innovation, leadership and strategy, acquiring five key geospatial firms in just over two years. The firm has flown more than three million square miles of lidar and imagery; has completed hundreds of topographic lidar missions for local, state and federal contracts; and continues to support multiple agencies and initiatives, including the USGS 3D Elevation Program. In addition, Woolpert has executed several topobathymetric lidar data collections in the last two years—including the coastlines of Alaska, Hawaii and the Commonwealth of the Northern Mariana Islands—to fulfill contracts with USACE, USGS and NOAA.

The firm owns and operates a fleet of aircraft, vehicles and sensors while partnering with industry giants like Esri, Google and Planet to provide novel, customer-focused solutions.

"Woolpert's recent experience has allowed us to create innovative airborne lidar solutions when off-the-shelf products fall short of customer requirements," Woolpert Senior Vice President Joseph Seppi said. "These investments are raising the bar and moving airborne lidar bathymetry forward as a growth area for Woolpert and the rest of our industry."

Research and development

So, how high can you fly and still collect lidar bathymetry? The response was to build a prototype system to collect at

10,000 feet that incorporated both tactical and civil operational requirements.

This new multispectral, multichannel lidar system emits green light to collect seafloor data and infrared light to collect topographic data, while simultaneously collecting high-resolution aerial images along a coastline. In addition, by collecting information on the Raman return, users can determine whether the data represents land or turbid water.

Most bathymetric lidar systems collect data at altitudes between 400 and 600 m, which is between 1300 and 2000 feet. Although collecting data from 10,000 feet is common for topographic systems, it is extremely challenging for bathymetric systems due to energy losses incurred when crossing the air/water interface and spreading light, which penetrates through the water column to reflect off the sea bottom. Woolpert wanted to collect bathymetric data at 10,000 feet to increase efficiency and flight safety for topobathymetric collections.

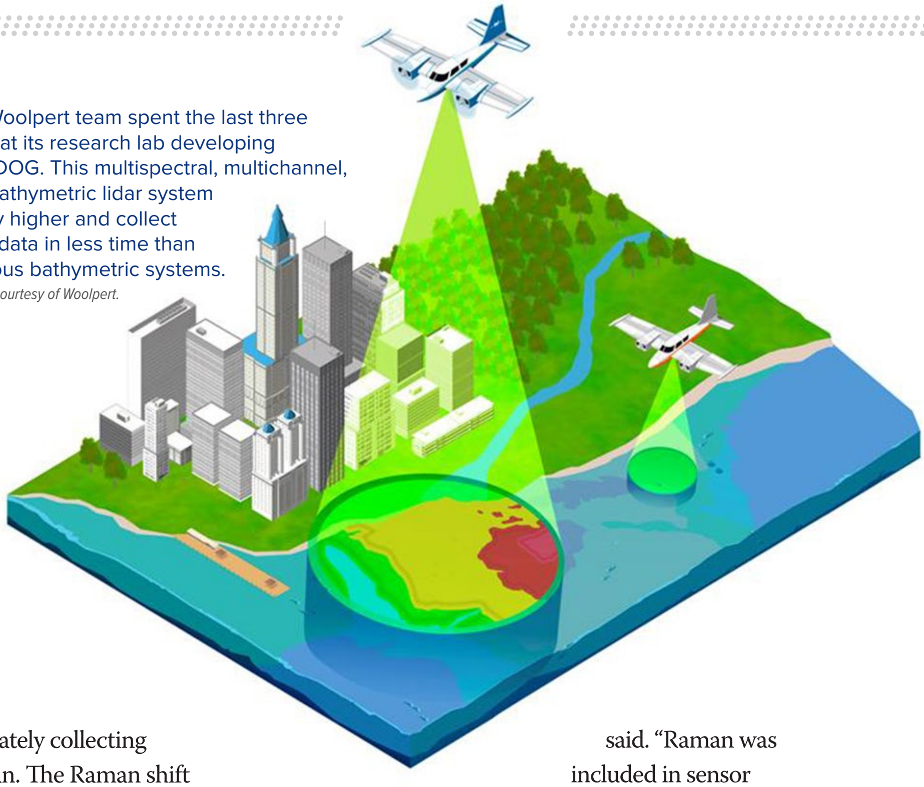
To accomplish this, the Woolpert team spent the last three years at its research lab developing BULLDOG, a multispectral, multichannel, topobathymetric lidar system that can fly higher and collect more data in less time than previous bathymetric systems. The patented lidar system maximizes the use of three different wavelengths of light—532, 647 and 1064 nm—by distributing them into five distinct detector channels designed for shallow water, deep water, Raman and infrared. The infrared light is further split into a linear mode and Geiger-mode channel utilized specifically for the sea surface and topographic measurements.

The team found that the biggest challenges were designing and engineering a flexible prototype that can collect lidar bathymetry from 10,000 feet while accurately collecting Raman. The Raman shift is the energy generated around 647 nm when the green light of the bathymetric laser interacts with water and shifts into a longer wavelength. The Raman signal can be used to accurately determine the water surface location when the water surface is very calm, mirror-like, or during night collections, and can aid in discrimination between land and water returns, which is critical to the accurate calculation of water depth.

However, Raman is an extremely weak signal. From 10,000 feet, simulations predicted single-digit photon returns, suggesting that the prototype had a 50/50 chance of Raman detection. Throughout simulations, modeling, design and testing, a focus was placed on noise reduction within the optical and electrical chain. Noise reduction coupled with a highly efficient telescope design contributed to successfully detecting Raman during engineering flights.

"With the Raman signal, we're able to determine if things are wet," Smits said. "Raman was included in sensor development in the 1980s and '90s, but it was omitted from the current generation of sensors due to both size, weight and power (SWaP) constraints and implementations of additional sea-surface detection capabilities. We anticipate being able to detect and use the Raman signal to do things like land/water discrimination. If we're flying at night and can't take high-resolution images, the Raman signal can be a differentiator as to whether or not a particular laser shot is on land or water."

BULLDOG can collect over a half-mile-wide swath of data at 10,000 feet in an aircraft traveling at 160 knots. At that altitude, flying in a straight line, BULLDOG can collect approximately 100 square kilometers of coastline every 40 minutes. In addition to manned aircraft, the initial design supports the ability to configure the system to support unmanned operations. It would require another spiral development to fully implement and test unmanned configurations.



The Woolpert team spent the last three years at its research lab developing BULLDOG. This multispectral, multichannel, topobathymetric lidar system can fly higher and collect more data in less time than previous bathymetric systems.
Graphic courtesy of Woolpert.

This ability to fly higher and still collect high-resolution topobathymetric lidar data also requires a more powerful laser than is used in the topobathymetric lidar systems currently on the market. The research and development team, therefore, built the BULLDOG system around a custom 100-watt laser and custom thermal management unit. This laser requires more power and a more robust cooling system than other topobathymetric lidar sensors. Since lasers are inherently unstable, the research team was challenged to create a stable thermal environment for the system to work properly on an aircraft. If temperatures fluctuate outside set parameters and the laser's energy fluctuates, the radiometric and system performance could be impacted.

Drawing on these lessons learned from decades of sensor ownership, operations and development experiences, the team created the BULLDOG system with the capability of real-time data processing, exploitation and dissemination (PED). This data-processing engine is designed to create 3D point clouds that can be colored by various attributes such as depth and Total Propagated Uncertainty (TPU). Testing is underway to allow the system's integrated software to transmit data and information in near real time to systems on the ground, enabling analysts and decision-makers access to time-sensitive information.

Numerous applications for this technology have been developed with the needs of Woolpert clients in mind, and therefore range from priorities set forth by federal agencies such as USACE, U.S. Navy, NOAA and USGS, to state and local governments and agencies, military purposes, and everything in between. Continued research and development efforts will focus on both civil and commercial operational requirements, including reduced SWaP and multiple flying altitudes.

Moving forward

Accurate bathymetric data is expected to be an essential resource in safe navigation and decision-making for coastal mapping and charting, coastal resilience and management, and disaster response for years to come. The BULLDOG system was conceived to address this requirement by and for those who understand it. This approach will become increasingly prevalent moving forward.

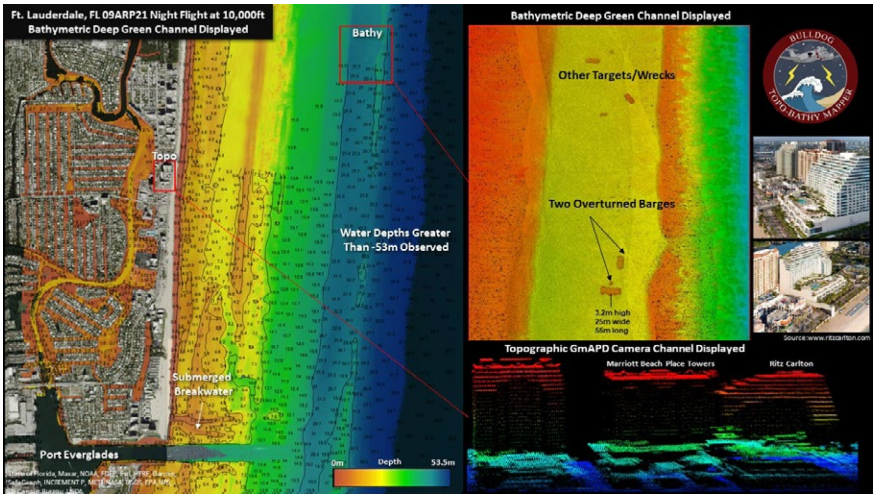
"We have been excited to see early results from this new system and look forward to a full system characterization over the next year," Wozencraft said. "Higher altitude not only increases data collection efficiency but also opens up areas in which we are able to survey, like high coastal terrain, and real-time data processing speeds up delivery of products to our customers."

Woolpert Senior Vice President Jeff Lovin said working with lidar in the field for more than 20 years and using a wide array of sensors was crucial to the team's ability to create this research and development lab and to build a sensor that fills this needed geospatial niche.

"Our focus on our clients' requirements has enabled us to customize products and services to address those needs efficiently and effectively, effectively, reducing the time it takes to produce actionable information," Lovin said. "This ability to engineer, build, deploy, collect, and deliver data and information is what sets Woolpert apart."

Dr. Nathan Hopper is a project manager in Woolpert's facility in Bay St. Louis, Mississippi, focused on the firm's maritime market.

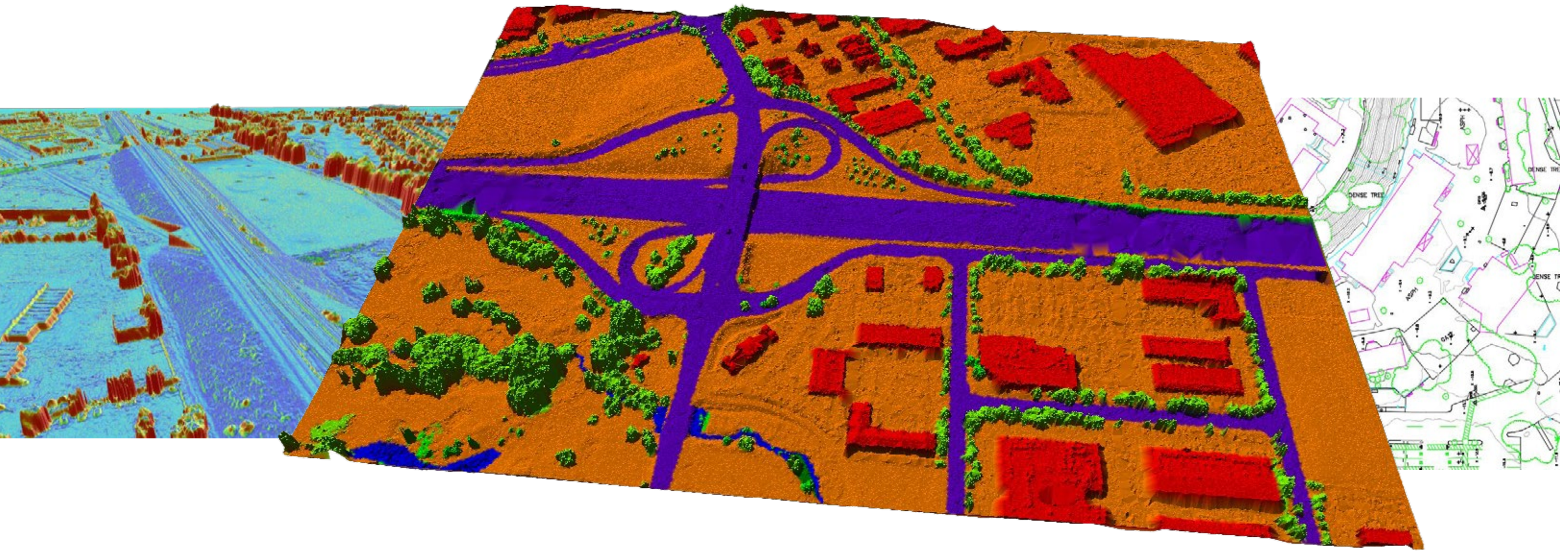
Michael A. Harper is a senior strategist supporting Woolpert's rapidly expanding geospatial sector, working between the firm's Bay St. Louis, Mississippi, and Arlington, Virginia, offices.



Topographic and bathymetric lidar data was collected on April 9, 2021, in Fort Lauderdale, Florida. The bathymetric data was overlaid with charted depths and contours for comparison.
Image courtesy of USACE/JALBTCX.

GeoWing Mapping Prospers with UAV-Photogrammetry

Bay Area startup executes lidar projects through partners



On a recent visit to several Bay Area lidar players[1], I was privileged to meet up with Rebecca A. (Becky) Morton, co-founder and CEO of GeoWing Mapping Inc., a small company offering UAV-photogrammetry and lidar services. GeoWing is based in Richmond, California. I was interested in the secrets of the company's success and its approach to lidar data acquisition and processing.

1 lidarmag.com/2021/09/14/green-green-my-valley-now/

BY STEWART WALKER

LM: Please give a history of your company.
BM: GeoWing Mapping, Inc. (GeoWing) was founded in January 2015. We are focused on providing aerial mapping solutions for engineering, environmental and land use applications. We are experienced in utilization of large format aerial systems as well as unmanned aerial systems and our goal is to provide the best tool and approach for each unique project.

LM: Please tell us about the current employees.
BM: The company owners are Rebecca A. (Becky) Morton, President and CEO, and Alan M. Mikuni, Vice President and CFO. Becky and Alan share responsibility for financing, hiring, and management of resources. Alan Mikuni is a California Professional Engineer and ASPRS Certified Photogrammetrist. Becky Morton is an ASPRS Certified Photogrammetrist and Certified Mapping Scientist.

James Berglund has been with GeoWing since 2017. He started as a project manager responsible for map production and business development. He currently holds the position of Vice President, Business Development. James has worked in the geospatial industry for over 22 years. He has extensive experience in photogrammetric mapping, GIS, CAD and lidar.

GeoWing Mapping headquarters in Richmond, California, just to the northeast of the Bay Bridge.

Becky Morton (left) and Alan Mikuni (right), co-founders of GeoWing Mapping.

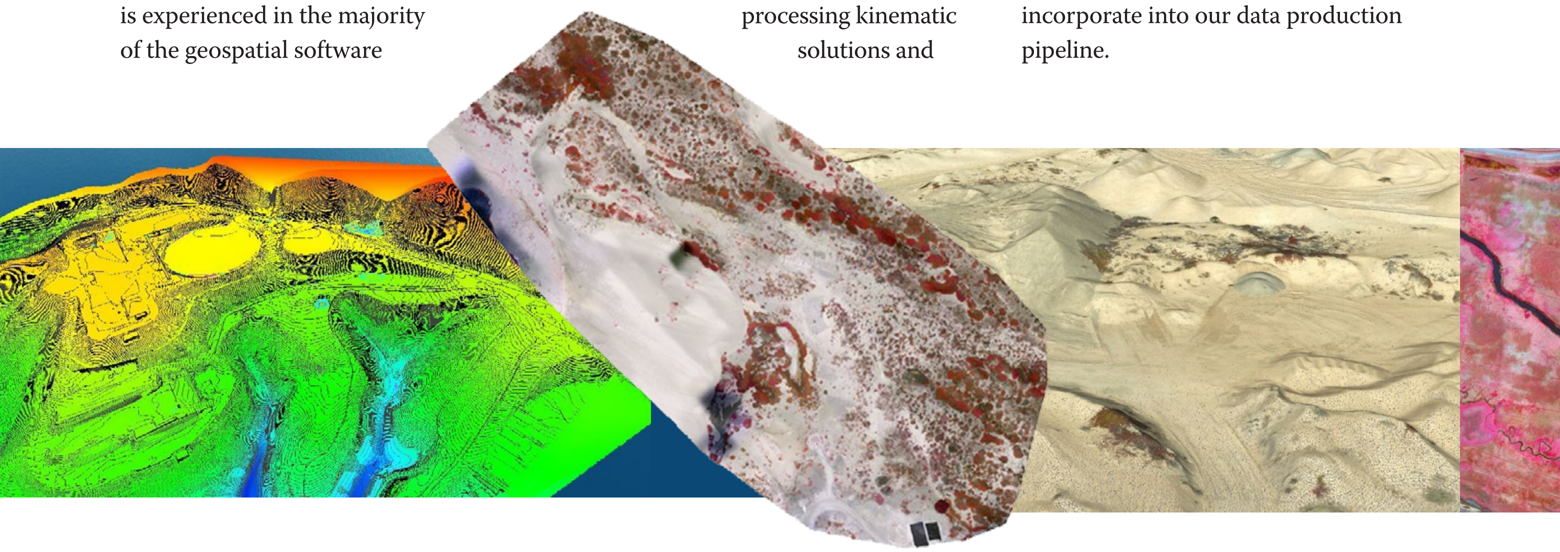
Gwendolyn (Gwen) Gee started working part time with GeoWing in 2015. She is a California PLS and a Certified Federal Surveyor. She was formerly County Surveyor for Santa Clara County in California. She serves as Survey Manager for GeoWing.

GeoWing has two part-time and one full-time drone pilots. Harley Milne and Mark Hull are experienced UAS pilots who have worked with GeoWing since its inception. Cyrus Khambatta began work at GeoWing in 2020 and is training under Harley and Mark. His educational background includes computer science, GIS, GPS, and environmental science. He is an FAA Part 107 licensed pilot, is experienced in the majority of the geospatial software programs and provides data production services at GeoWing.

LM: Could you summarize the equipment you have at your disposal?

BM: GeoWing has standardized on DJI unmanned aircraft at this time. We own and operate several systems from the smaller Phantom drones to the Enterprise systems such as Inspires and Matrices. In addition to the drone platforms we incorporate geopositioning equipment such as the AirGon LOKI system, which provides post-processing kinematic solutions and the DJI M210-RTK and M300 systems for real-time kinematic solutions. The sensors that we operate include three-band RGB cameras DJI Zenmuse X4S, X5, X7, P1; multispectral cameras such as the MicaSense RedEdge and Altum; and thermal cameras such as the DJI XT2 and H20T.

GeoWing is experienced in project design and map production for projects using manned aircraft and/or lidar data acquisition. When these are required, we work with several strategic partners to provide acquisition, which we then incorporate into our data production pipeline.



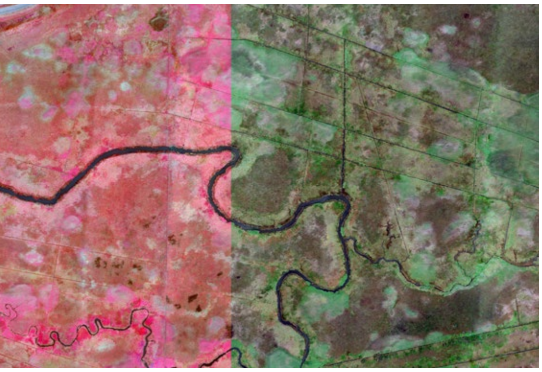
The GeoWing Mapping workforce at headquarters.

Our company is licensed and experienced in providing ground control surveys for mapping projects. We own GPS/GNSS receivers and we provide the control networks for our projects or we provide guidance on requirements to clients who provide their own survey.

LM: What software do you use?
BM: We have a large variety of software products at our disposal, chosen with an eye on economy but always with fulfillment of customers' requirements as the first priority. For our UAS-photogrammetry, of course, we use Pix4D and Metashape, sometimes running the same project through both and selecting the result that we think better fits the data. We have had good experiences performing strip alignment of lidar blocks with software from BayesMap Solutions and we have formed a fruitful relationship with founder and CEO Dr. André Jalobeanu. We also use the Remotely Operated Agriculture Mapping product (ROAM)[2] for some precision agriculture projects. Sometimes our employees work at customer sites and gain experience of other software.

LM: What is special about GeoWing? What would you say are your firm's greatest strengths?
BM: In addition to the depth and breadth of the company's technical expertise and experience, GeoWing's strength comes from the relationship among the employees. We are a small

2 ruralmessenger.com/kansas-news/agriculture/remotely-operated-agriculture-mapping/



Becky and Alan surveying a ground control point.

company and we rely upon everyone's commitment and skills to accomplish each project. We have fun.

LM: Your website lists a formidable range of clients. Are there particular markets you are aiming at? Is there any such thing as a "typical job"?
BM: We do have a "typical job" category which makes up the bulk of our work - high-resolution, high-accuracy UAS-photogrammetry. These jobs are usually under 1000 acres and require mapping to produce DTM surfaces, 1´ contours and full planimetric map collection as well as orthophotography with a resolution of 0.1´ or better. There are multiple markets that require this "typical" list of services, e.g., land use/land development, environmental, utilities, and transportation.

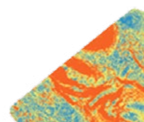
Approximately 50% of our projects require a manned aircraft approach due to the size and/or complexity of the project area. In those circumstances, we perform project design and work with acquisition partners to provide the aerial data, which we then integrate into our standard mapping operations.

In addition to photogrammetric projects, we are always pleased to land a project that requires some other challenging aspect such as 3D modeling, multispectral orthophotography, drone monitoring, volumetrics, close-range data capture, thermal, standards and specifications consulting, quality control/assurance, etc.

GeoWing Mapping and its partners.

LM: You were always adamant that you would not include lidar in your capabilities owing to its cost and the resulting risk in the event of a UAV crash. Has the falling cost of lidar sensors changed your mind?
BM: We are pleased with our current model of operation, which provides the flexibility to contract for lidar acquisition rather than owning the equipment. Fortunately, we have several highly qualified strategic partners, such as SkyIMD, Inc. of Richmond, California, and Hawk Aerial, LLC of Napa, California, so we are in a position to contract out lidar data acquisition from both UAVs and crewed aircraft.

LM: Yes, indeed, you have successfully completed lidar projects through your relationships with partners. There are seven lidar clients on your website. Could you please say more about this?
BM: GeoWing's lidar services include direct-contract



clients and sub-contract clients. Our employees are highly experienced in performing lidar classification and lidar mapping and therefore part of our business model includes offering sub-contract services in that area. In addition, we have been fortunate to provide some direct-contract lidar services, where we manage the project from initial project design through mapping and final lidar deliverables. Examples of the direct-contract clients are AECOM and the City of Sausalito. AECOM contracted with GeoWing to provide a turn-key solution consisting of lidar mapping, bathymetric integration and orthophotography on the 284-acre Upper Truckee River Restoration Reach 5 Project for the US Forest Service. GeoWing was the prime contractor with the City of Sausalito's Lidar and Ortho Project in 2017, which included lidar mapping, contours, and orthophotography over the Sausalito city limits in support of the development of a Sausalito Storm Drain Master Plan.

LM: Do you see more lidar in your future?

BM: We predict more lidar mapping in the future for GeoWing. Lidar provides the best mapping data in many scenarios and the cost is coming down, therefore we should be able to offer lidar more often and still hit the client's budget. I believe the client demand will increase as more and more clients have experience working with lidar data sets.

LM: You left a career in larger geospatial enterprises, including Horizons and Towill, to found your company. Has the result been a fulfilling experience? Would you advise others to take this course?

BM: Founding GeoWing has been a very fulfilling experience. I believe this sentiment is shared by my business partner, Alan Mikuni. Every project that is delivered with high accuracy, quality mapping, and beautiful imagery provides satisfaction. The frequency with which clients come back to us based upon the professionalism and timeliness of our service *is* rewarding.

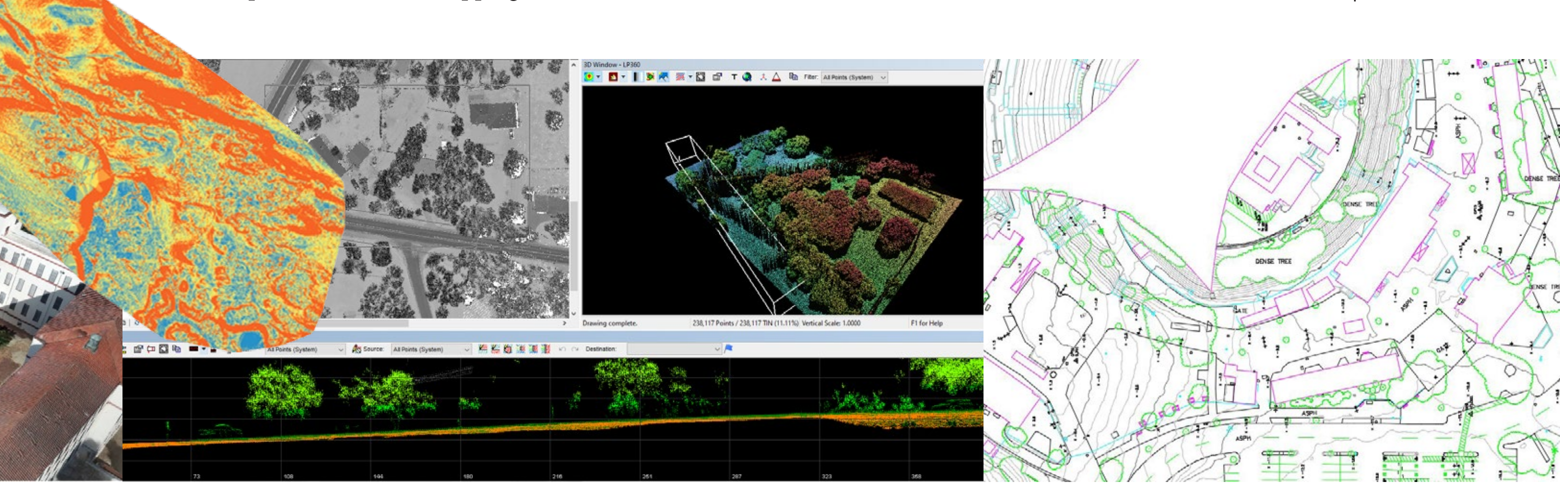
LM: Lastly, you have been extremely active in ASPRS, though I'm sure your responsibilities at GeoWing have made this very difficult. I know that you have been involved in the development of ASPRS standards related to the procurement of geospatial services[3]. Do you have plans to do more of this in the future?

BM: ASPRS involvement has been one of my best career path choices. I have received far more than I have given from ASPRS and the incredible contacts and mentors that came from the many years of participation. I am currently participating and contributing through board membership at the regional ASPRS level. I believe this is where I will continue to serve for the remainder of the time that I am involved in the industry.

LM: Becky, thank you very much indeed for providing this compelling cameo of GeoWing Mapping. *LIDAR Magazine* wishes you every success in the future as your firm expands.

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

3 Morton, B., 2015. Intro to the ASPRS guidelines for the procurement of geospatial mapping products and services, *Photogrammetric Engineering & Remote Sensing*, 81(8): 605, August 2015. The full guidelines may be viewed at asprs.org/a/society/committees/standards/Combined_Procurement_Guidelines.pdf.



Real-Time Surveying to Support NASA's Artemis I Launch

PREPARING FOR MISSION RAISES UNIQUE SURVEYING CHALLENGE—A MOVING OBJECT

Figure 1: CT fully loaded with concrete blocks. Total weight for this pass was 25 million pounds.
Photo credit Gary McDaniel.

NASA plans to launch the Orion spacecraft on a 26-day mission around the moon via the Space Launch System, its new heavy-lift rocket, in late 2021. The unmanned Artemis I flight is the first in a line of complex missions aimed at enabling exploration of the Moon and Mars.

But before the Orion spacecraft can be launched into space, it must first be moved from the Vehicle Assembly Building to the launchpad at the Kennedy Space Center.

Enter the Crawler-Transporter (CT; **Figure 1**), four connected building-sized vehicles on rolling tracks, which, when loaded with the Orion and its mobile

BY BRYAN **MERRITT** AND GARY **MCDANIEL**

Figure 3: Crawlerway road after the CT has passed over. This shows the effect on the crawlerway, but it was determined before the survey began that the movement of the CT could affect elevation anywhere in the zone of influence.

Photo credit Bryan Merritt.

launcher, will carry over 25 million pounds. That's the equivalent of 1020 school buses, one of the heaviest overland loads ever recorded.

The challenge of moving 25 million pounds

As the CT moves along the crawlerway (**Figure 2**), it has the potential to sink into the ground, tip and allow its payload to fall off (**Figure 3**). The resulting damage could put the entire Artemis I mission in jeopardy, not to mention the more than $20 billion NASA has invested in the Orion.

To address this risk, the agency partnered with engineering firms Langan and Jones-Edmunds to monitor ground deformation under the CT in real time. The solution Langan developed was a surveying process for taking measurements on both sides of the CT simultaneously, collecting data every 10 feet along the 4.1-mile crawlerway.

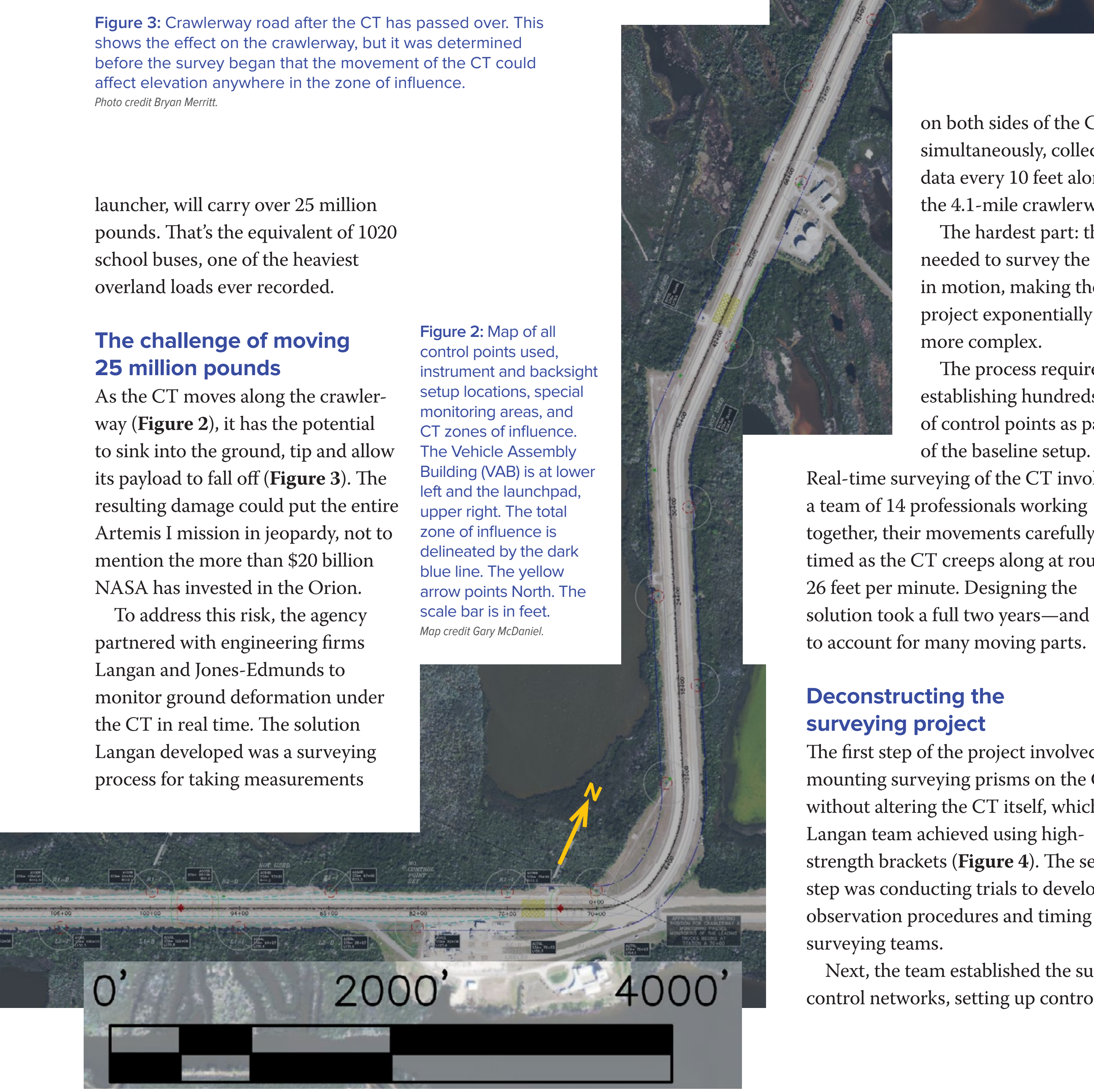


Figure 2: Map of all control points used, instrument and backsight setup locations, special monitoring areas, and CT zones of influence. The Vehicle Assembly Building (VAB) is at lower left and the launchpad, upper right. The total zone of influence is delineated by the dark blue line. The yellow arrow points North. The scale bar is in feet.

Map credit Gary McDaniel.

The hardest part: they needed to survey the CT in motion, making the project exponentially more complex.

The process required establishing hundreds of control points as part of the baseline setup. Real-time surveying of the CT involves a team of 14 professionals working together, their movements carefully timed as the CT creeps along at roughly 26 feet per minute. Designing the solution took a full two years—and had to account for many moving parts.

Deconstructing the surveying project

The first step of the project involved mounting surveying prisms on the CT without altering the CT itself, which the Langan team achieved using high-strength brackets (**Figure 4**). The second step was conducting trials to develop observation procedures and timing for surveying teams.

Next, the team established the survey control networks, setting up control

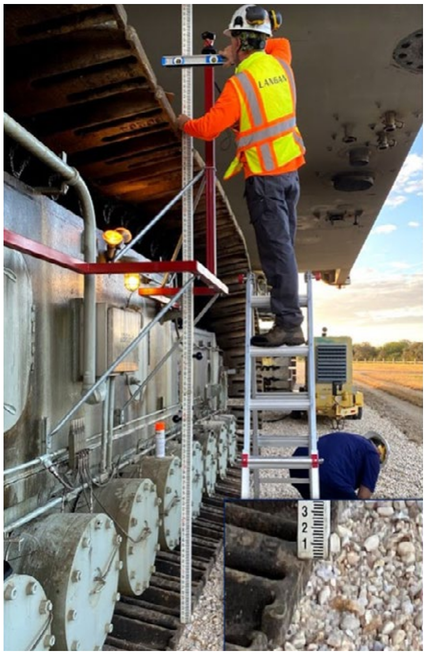


Figure 4: Finished bracket mounted to the CT truck (left)— 2” square tubing 11 feet long, 4 feet high, supported with 3/4” steel tubing, all attached without damaging or altering the surface of the CT. Measuring the height of prism relative to the crawlerway road underneath the CT trucks (center). Testing prism bracket and potential monitoring procedures during a planned move of the CT (right).

Photo credits Bryan Merritt (left), Ryan Wolf (center) and Lee Stirling (right).

points every 600 feet to measure location and elevation to one one-hundredth of a foot (**Figure 5**).

The primary control network with over 100 control points was established prior to the monitoring surveys. GNSS was used to determine the horizontal positions of these points and a closed differential level loop run to determine their elevations.

Trees and brush in the area mean that surveying stations must sit within the CT’s zone of influence (**Figure 6**), defined as the theoretical distance from the CT within which, according to mission engineers’ estimates, the soils could potentially be disturbed by the movement of the CT.

There was only one problem

Inside the CT’s zone of influence, the weight of the CT could move the ground under the surveying equipment itself, impacting the accuracy of the data. To account for this risk, Langan set up a secondary survey control network outside the zone of influence, effectively doubling the number of measurements taken.

Figure 5: Vertical control survey: a closed digital level loop was used to establish elevations for all control points set (left). Control level run started from an NGS monument near the VAB (center and right).

Photo credits Ryan Wolf.

Figure 6: Vegetation close to the crawlerway road sometimes meant that to get outside the CT zone of influence levels had to be set up 40 or 50 feet into the trees.

Photo credit Gary McDaniel.

Ideally we would have been able to put all our control points outside the zone of influence. Owing to years of vegetation growth, however, for some locations it would have been necessary to clear large amounts of vegetation to be able to see the CT (**Figure 6**), which was not allowed by NASA—or we could put the control points closer to the CT, and within the zone of influence, but monitor the ground for any "influence" by the weight of the CT from the secondary survey control network. To monitor the ground underneath the total stations we would set up a differential level that was outside the zone of influence and take readings using a custom-made self-supporting level rod (**Figure 7**). The idea was to take an initial reading of the level rod before the CT moved too close to the total station and make readings of the level rod, which was regarded as stable, continuously until the CT was past the total station and no longer influencing the ground at the total station location. We did not record any ground movement during any of the monitoring passes, but we were prepared to detect any ground movement had it been an issue.

During the monitoring survey (**Figure 8**) each total station was set on its assigned primary control point(s) and used to observe a 360° prism set at a fixed height on another primary control point. The 360° prisms on fixed height rods were used to allow multiple total stations to simultaneously use each "backsight prism" to orient the survey and could be also be used as quality control checks by other total stations.

Once the CT was within range the instrument operators would look through the total station to fix the crosshairs upon the 360° prism mounted to the CT. This was needed to allow the robotic total station to automatically and continually track the prism and

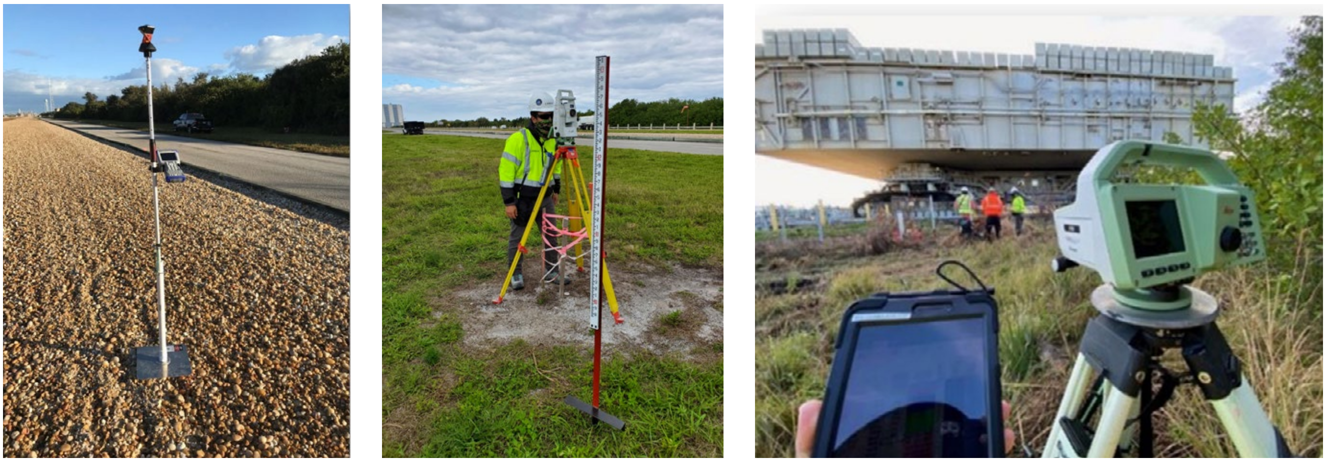


Figure 7: Monitoring the elevations. 12" square aluminum plate fixed to the bottom of a survey rod to allow for a measurement of the top of the crawlerway road surface, ensuring the rod tip did not fall between individual rocks (left). Bespoke mount for level rod to monitor ground at an instrument setup within the CT zone of influence (center). Monitoring the ground at an instrument location outside the CT zone of influence (right).

Photo credits Brian Merritt (left), Gary McDaniel (center and right).

Figure 8: The monitoring process. Top-left: Langan survey crew in position ahead of the CT, prepared to monitor once the CT moves within range. Top-right: CT being monitored from a control point setup within the zone of influence. Lower-left: One member walking with CT calling out station marks, one at total station taking measurements to the prism mounted to the CT, one at the instrument recording data in shared spreadsheet on a field tablet, one using a level placed outside the CT zone of influence to monitor the ground underneath the total station. Lower-right: Station markers were set every 50 feet along the entire length of the crawlerway.

Photo credits Ryan Wolf (top-left), Gary McDaniel (top-right, lower-left, lower-right).

make constant calculations about how far the prism was from its last recorded position. Once a distance of 10 feet from the previously recorded position was achieved, the data collector would store the prism coordinates (X,Y,Z) and use the newly stored position as the updated reference position to prepare for the next upcoming measurement. This procedure allowed us automatically to take measurements of the CT every 10 feet utilizing the technology of the robotic instruments. Team members would then enter the elevation of the recorded measurement into a spreadsheet that was used to aggregate the measurements from all four total stations being used.

Dry run

The last step—a dry run of the surveying process—is where the team's preparation was put to the test. Four robotic total stations are used, with two crews on each side of the CT leapfrogging each other as the CT moves down the path. While one crew measures the location and elevation of the surveying prism on the CT, the other moves into position for the next measurement.

Langan sends the measured data to a shared spreadsheet within seven seconds, using a formula to determine whether any ground deformation detected is within normal limits. At that point, the Jones-Edmunds team is responsible for deciding whether it's safe to keep rolling or whether the CT must stop.

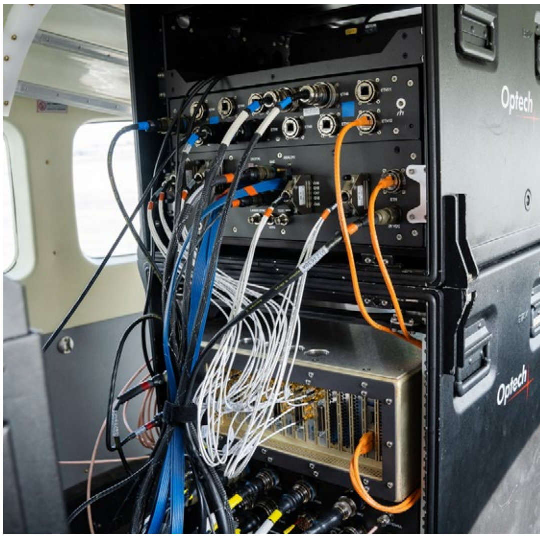
The final test, however, will come when the CT finally carries the Orion to the launchpad. That day will represent years of preparation in support of a groundbreaking mission decades in the making, one that will help humans reach new frontiers in space.

Social posts

Learn how Langan is helping prepare for the upcoming @NASAArtemis #space mission #surveying #engineering #NASA; or how Langan is using real-time #surveying of a moving object to support the @NASAArtemis #space mission #engineering #NASA

Bryan Merritt, PLS/PSM is a Professional Land Surveyor licensed in New York and Florida. He serves as a Senior Survey Manager in charge of Florida and the Caribbean for Langan Engineering and Environmental Services Inc. He has been surveying since 1982 and has an extensive background in all facets of surveying methodologies.

Gary McDaniel, PSM started surveying in 2012 after teaching high school physics and chemistry for seven years. He earned his Professional Survey and Mapper License in Florida in 2019 and has been a licensed sUAS pilot since 2017.



APPLYING THE LATEST TOPOGRAPHIC AND BATHYMETRIC LIDAR TECHNOLOGY **IN SUPPORT OF OUR CLIENTS' NEEDS**

Amar Nayegandhi, CP, CMS, GISP
anayegandhi@dewberry.com
813.421.8642

Dewberry®
www.dewberry.com

A New Hybrid Product Approach:

Aligning Project Specifications with UAS, Photogrammetry and Lidar

Woolpert makes best use of multiple data types in roadway surveys

This paper discusses research on a new and creative method of merging geospatial data from differing backgrounds and with varied accuracy specifications. The following topics are covered:

- Definition of project zones and identification of the data requirements for each zone
- Selection of zone-specific technology for data acquisition
- Steps for producing a hybrid product such as accuracy verification, data preparation and product development
- Case studies and project examples

We conclude that demand for geospatial data is increasing, and hybrid data fusion is among the best methods for producing accurate models. This requires considerable analysis, especially with respect to data accuracy, to ensure the correct approach is taken. Aside from providing evidence for the usefulness of emerging geospatial technologies in transportation projects, the benefits derived from the new hybrid product approach include cost and time savings, critical for clients with constrained budgets.

Background

Continuously declining construction project funding poses a great challenge for agencies attempting to finance new projects and/or maintain existing ones. With constrained budgets, many agencies struggle to meet their development objectives and are searching for creative ways to advance their projects. Recognizing clients' need for survivability and resilience, Woolpert researched creative methods for enabling goal achievement under strict budgets.

As the capabilities of geospatial data acquisition technologies are refined over time, more products from different sensors can relate to each other in terms of data quality and accuracy—making it easier for project managers and engineers to seamlessly integrate different data sources into their projects.

The term data fusion, in a general sense, is used to describe the combination of available geospatial data and is practiced only as a reaction to an immediate need or incidental data finding. The data fusion discussed in this paper is different—it focuses on the early stages during project planning and design. It describes the proactive adaptation of a data evaluation strategy to stand on the synergy between disparate data sources, making these findings the pillars for project design and cost estimation.

BY QASSIM **ABDULLAH** AND TOM **RUSCHKEWICZ**

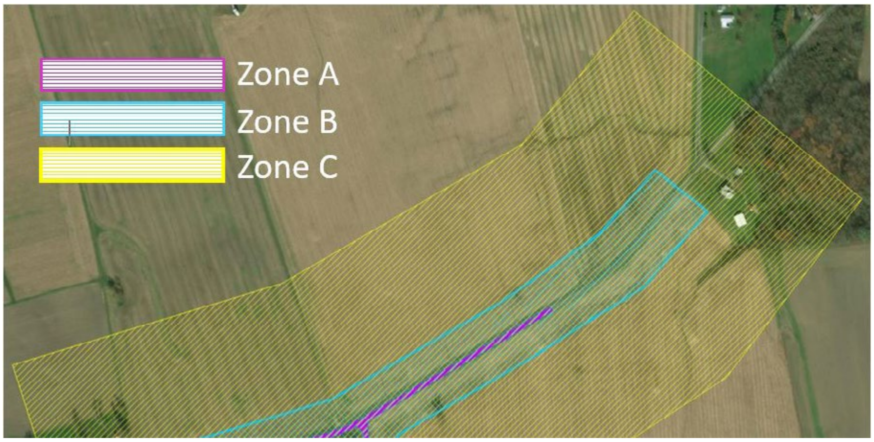


Figure 1: Zones A, B and C.

Data specifications and project zoning

Today's engineers and planners can use the concept of data fusion to design their projects, saving valuable resources while assuring the promised outcome. Woolpert has successfully executed projects containing varied geospatial data sources with multiple specifications acquired by different technologies, all merged to produce a seamless product that serves the planning and design phases.

Considering the requirements for planning, designing and engineering a transportation corridor (e.g., roadway construction or improvement), three types of data are needed for the project zones identified below.

Zone A: central region of the right-of-way

Represented by Zone A (**Figure 1**), this part of the right-of-way (ROW) is dedicated to construction and maintenance of the main roadway and necessary outer roadways, entrances and crossroads. This area requires the most accurate geospatial data as it will be used for designing the road profile or improving the existing road. Traditionally, it is surveyed using traditional field surveying techniques, newly contracted aerial surveys with high-resolution imagery or helicopter-based dense lidar data, as well as through lidar-based mobile mapping systems (MMS) for road improvement.

Zone B: edges of the ROW

Represented by Zone B (**Figure 1**), the outer limits of the ROW are reserved for utility adjustments and maintenance activities. This area's survey requires less accuracy than that of Zone A, but more than that of Zone C. Traditionally, this area is surveyed using standard field surveying techniques as it is not suitable for vehicular survey equipment like MMS.

Zone C: extended project basin

Zone C (**Figure 1**) is the area surrounding the corridor path where the drainage pattern is evaluated and a hydrological model is analyzed to determine the impact of the watershed hydrography on the corridor. Depending on the roughness of the terrain, less accurate data may be suitable. Traditionally, this area is surveyed using newly contracted aerialimagery or lidar.

Technological components

Three technologies are used for gathering data about the aforementioned project zones, listed below with their strengths and weaknesses.

MMS

MMS is a mapping system with a lidar sensor and multiple cameras positioned on top of a truck or van to provide 360°coverage of lidar data and imagery. MMS is the most efficient system for design-grade accuracy. It provides a detailed 3D surface (point cloud) with a density of up to 6000 points per square meter (PPSM) and a vertical accuracy that exceeds 1 cm root mean square error (RMSE). The weaknesses of MMS are its limited range (usually around 200 m), high cost and restriction to established roadways.

Unmanned aircraft system (UAS)

Although new, UAS is becoming an extremely versatile option for geospatial data acquisition. With the ability to carry lidar sensors and cameras on board, small UASs can provide high-resolution imagery ranging from 0.5- to 5-cm ground sample distance (GSD) and lidar data with point density ranging from 200 to 700 PPSM. UAS is a fine platform for data acquisition in zones A and B as it is a more affordable method than field surveying, MMS or even manned aircraft. UASs, however, are useful only for small projects and flying over non-participants is severely restricted by the Federal Aviation Administration (FAA). Additionally, due to the miniaturized sensors suited to this platform, the accuracy of the acquired data is compromised and may not be suitable for design-grade activities. This is exemplified in colorized 3D point

Figure 2: Colorized 3D models derived from imagery acquired from a UAS.

clouds derived from a consumer-grade aerial camera like the one used by UAS (**Figure 2**).

Manned aircraft

Manned aircraft survey (lidar and imagery) is the industry workhorse for wide-area data collection. Lidar data and imagery acquired from sensors on board manned aircraft are available across the United States and, in most cases, are available free of charge and can be downloaded from county GIS offices. Nevertheless, it can be costly to hire personnel for small roadway improvement projects, and limited accuracy may not support design-grade activities.

Case Study I: Petersburg/Overman road intersection improvement

With the goal of improving the intersection of Petersburg and Overman roads in Highland County, Ohio, the data fusion approach was used for the project's proof of concept (**Figure 3**). Woolpert used the following datasets:

Figure 3: Petersburg/Overman Road intersection improvement.

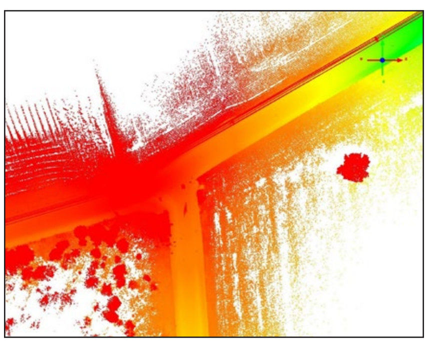


Figure 4: Point clouds from MMS (Zone A).

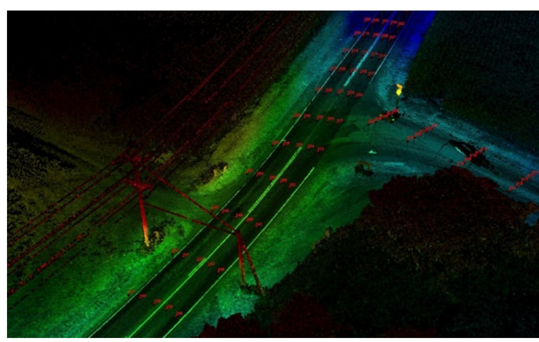


Figure 5: Point clouds from MMS (Zone A) and the derived second-generation checkpoints.

- Point clouds from MMS for the road pavement (Zone A)
- Point clouds and imagery from UAS for the outer limit of the ROW (Zone B)
- Existing lidar data from Ohio Statewide Imagery Program (OSIP) for the area surrounding the corridor path (Zone C)

Point clouds from MMS (Zone A)

Woolpert had previously conducted an MMS survey for the local transportation agency. **Figures 4 and 5** illustrate the MMS point clouds for a portion of that intersection.

Point clouds from UAS (Zone B)

The project team flew the UAS at 100 feet above ground level (AGL). **Figure 6** illustrates the UAS flight and the ground control points used to process the data. Imagery from the UAS flight was processed using Pix4D Mapper. **Figure 7** illustrates the point clouds generated from this imagery.

Lidar point clouds from statewide mapping program (Zone C)

Lidar data for Zone C was derived from OSIP and downloaded from the Ohio Geographically Referenced Information Program (OGRIP) website. **Figure 8** illustrates the point clouds for this project area.

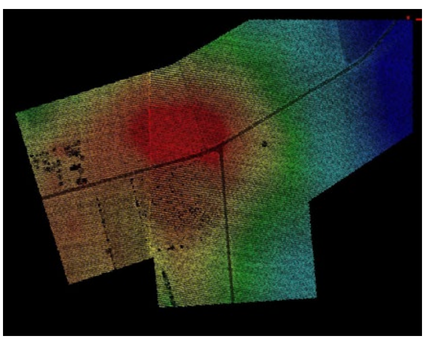


Figure 8: Lidar point clouds derived from OSIP (Zone C).

Figure 6: UAS imager centers (red circles) and ground control points (blue crosses).

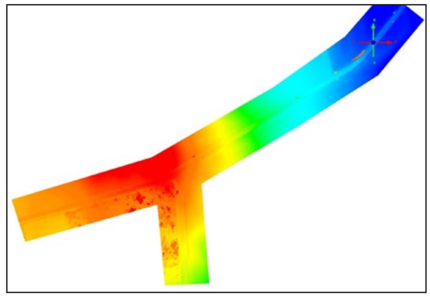


Figure 7: Point clouds generated from UAS imagery (Zone B).

Processing steps for the hybrid digital surface model (DSM) product

Stringent workflows should be followed when merging data to produce the hybrid DSM product. Below are the main steps for data processing:

- Accuracy verification
- Data preparation
- Product development

Accuracy verification

One of the most important activities is verifying the positional accuracy for each product used in the generation of the hybrid product. Different products used for the hybrid DSM may have different accuracies; however, such accuracies must be independently verified and documented in the metadata of the new hybrid product.

Accuracy verification of MMS data

Positional vertical accuracy for the MMS data was verified using 79 checkpoints surveyed with traditional differential leveling techniques. **Table 1** lists these results: the MMS data was accurate to 0.043 feet (0.013 m).

Number of Check Points	79	
Mean Error	0.023 ft.	0.007 m
Standard Deviation (StDEV)	**0.037 ft.**	**0.011 m**
Root Mean Squares Error	0.043 ft.	0.013 m
NSSDA Vert Accuracy at 95%	**0.085 ft.**	**0.026 m**

Table 1: Accuracy verification results for MMS data (Zone A).

Number of Check Points	73	
Mean Error	0.085 ft.	0.026 m
Standard Deviation (StDEV)	**0.130 ft.**	**0.040 m**
Root Mean Squares Error	0.154 ft.	0.047 m
NSSDA Vert Accuracy at 95%	**0.302 ft.**	**0.092 m**

Table 2: Accuracy verification results for the imagery-based DSM data, using surveyed checkpoints.

Accuracy verification of UAS data

Positional vertical accuracy for the UAS-derived DSM data was verified by two methods. Initially, 73 checkpoints were surveyed with traditional differential leveling techniques. **Table 2** lists these results: the imagery-derived DSM was accurate to 0.154 feet (0.047 m) with respect to the MMS data from **Table 1**, which the team proved accurate to 0.043 feet (see above).

Unlike a limited number of surveyed checkpoints, the MMS data for this type of accuracy verification provided an extensive and well-distributed network of checkpoints. In the mapping industry, this approach is usually referred to as the second-generation checkpoint

Number of Check Points	509	
Mean Error	0.080 ft.	0.024 m
Standard Deviation (StDEV)	**0.124 ft.**	**0.038 m**
Root Mean Squares Error	0.147 ft.	0.045 m
NSSDA Vert Accuracy at 95%	**0.289 ft.**	**0.088 m**

Table 3: MMS data-derived accuracy verification results for imagery-based DSM data.

Number of Check Points	197	
Mean Error	0.474 ft.	0.144 m
Standard Deviation (StDEV)	**0.161 ft.**	**0.049 m**
Root Mean Squares Error	0.500 ft.	0.152 m
NSSDA Vert Accuracy at 95%	**0.981 ft.**	**0.299 m**

Table 4: Accuracy verification results for OSIP lidar data.

approach. Elevations of 509 locations along the road, grouped in sets of five points per cross-section, were derived from the MMS DSM (**Figure 5**). These 509 points were used as checkpoints to verify the accuracy of the imagery-based DSM. **Table 3** lists these results: the imagery-based DSM was within 0.147 feet (0.045 m) of the MMS data.

Accuracy verification of OSIP lidar data

A total of 197 surveyed checkpoints located within Zone C were used to verify the vertical accuracy of lidar data from OSIP. The metadata for the downloaded lidar data states the vertical accuracy to be 0.5 feet (15 cm), which was verified using the 197 checkpoints in **Table 4**.

Data preparation

Once the project team verified the vertical accuracy of the various datasets, data processing preparations began. Data may need some, or all, of the following processing before it is merged:

- Reformatting
- Reprojecting
- Clipping and cropping

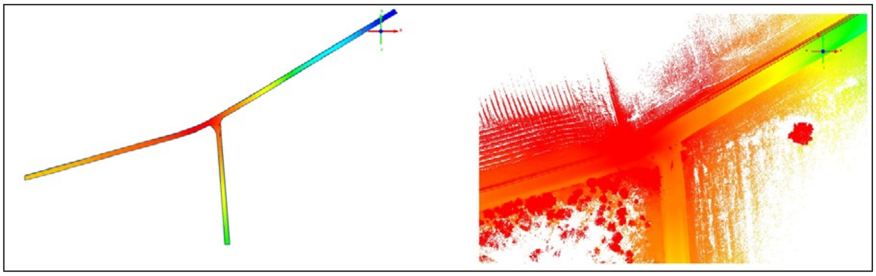


Figure 9: Zone A before and after clipping.

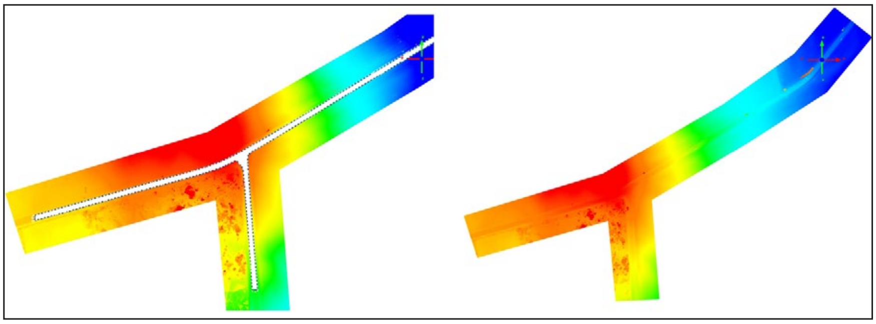


Figure 10: Zone B before and after clipping.

After the necessary reformatting and reprojection were completed, the data went through the following steps:

1. Clip MMS data to represent only roads and pavements for Zone A (**Figure 9**)
2. Clip UAS-based data to represent Zone B only (**Figure 10**)
3. Clip OSIP lidar data to represent Zone C only (**Figure 11**)
4. Merge OSIP lidar and UAS-based DSM (**Figure 12**)
5. Merge MMS lidar, OSIP lidar and UAS-based DSM to form a seamless dataset and hybrid DSM (**Figure 13**).

Product development and final deliverables

After the different datasets were merged, various products could be derived for planning and design activities. **Figure 14** represents one-foot contours generated

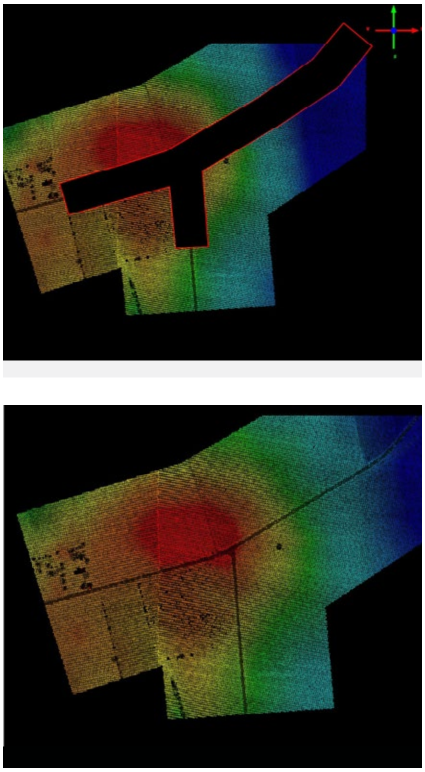


Figure 11: Zone C before and after clipping.

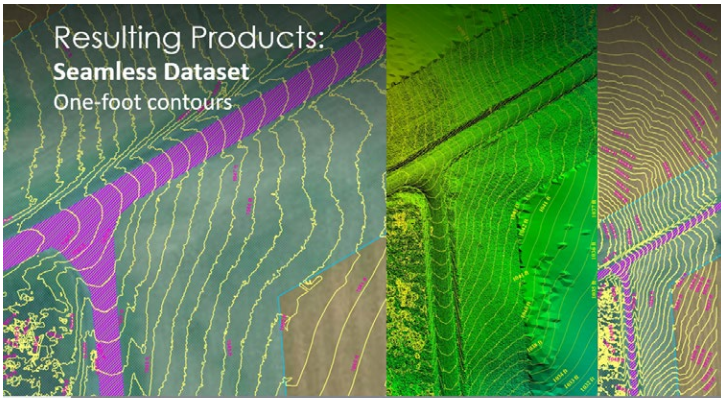


Figure 14: Seamless one-foot contours created from the hybrid DSM.

from the new hybrid DSM. Although the merged datasets appear as if they are one dataset, the data within each of the three zones (A, B and C) have different accuracies and should be labeled as such in the metadata (**Figure 15**).

Product Specification	Hybrid Product Accuracy**		
	Type A	Type B	Type C
Terrain surface accuracy as verified using independent check points	**RMSE$_v$ ≤ 0.06 ft.**	**RMSE$_v$ ≤ 0.10 ft.**	**RMSE$_v$ ≤ 0.50 ft.**

** Type A = MMS lidar , Type B = UAS imagery-based points cloud, Type C = State wide lidar program

Figure 15: Labeled metadata associated with the hybrid DSM.

Case Study II: UAS proof of concept for PennDOT

Woolpert acquired data using an eBee X RTK UAS to investigate its usefulness in supporting road design activities (**Figure 16**). The project team had previously acquired MMS data and 7.5-cm imagery using a manned aircraft for section 35 of SR80 to fulfill a contract requirement with Pennsylvania Department of Transportation (PennDOT). Imagery collected using the eBee X was used to generate the following products (**Figure 17**):

- Orthorectified mosaic with 2.5-cm GSD
- Imagery-based point clouds
- Digital terrain model (DTM)

The DTM was created photogrammetrically: the stereo pairs from UAS-based imagery were used to collect

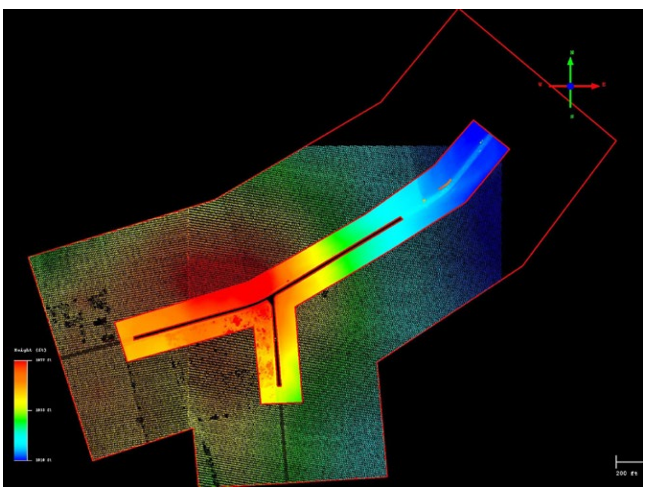


Figure 12: Merged OSIP lidar and UAS-based DSM.

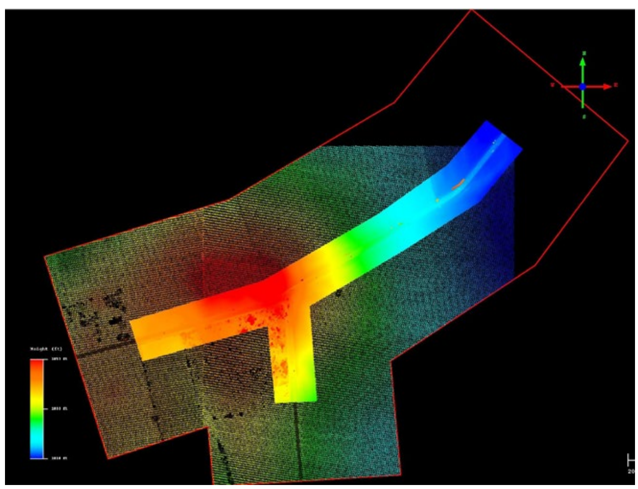


Figure 13: Hybrid DSM of three merged datasets.

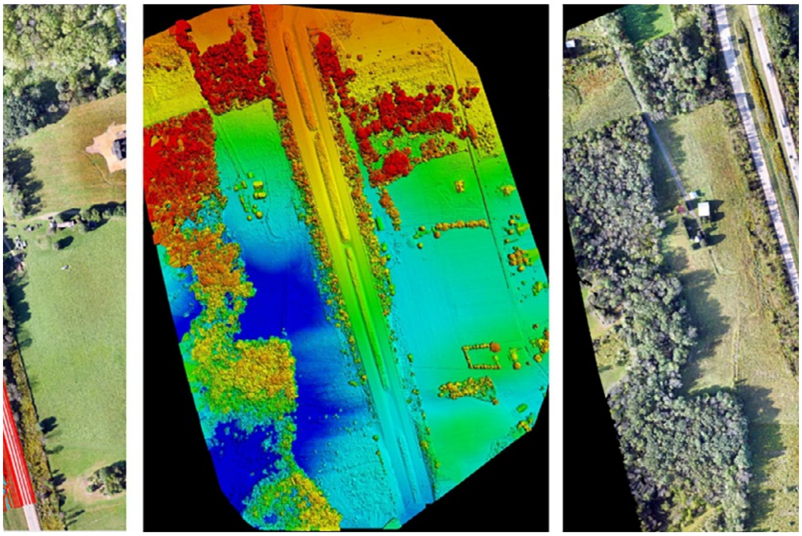


Figure 17: Products generated from UAS imagery (left, DTM; middle, point cloud; right, orthorectified mosaic).

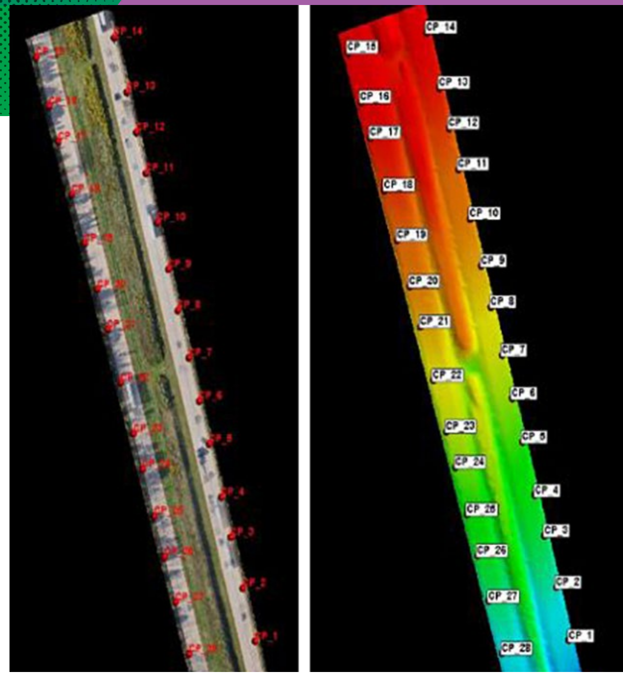


Figure 18: Checkpoint locations along SR80.

the DTM for the two bounds of the freeway. The stereo pairs met the high quality expected for photogrammetric mapping with no reported parallax.

Accuracy verification

The vertical accuracy of the photogrammetrically derived DTM was verified using the following datasets:

MMS data

Although the vertical accuracy is limited, lidar point clouds from an accurate MMS survey can be used to verify products derived photogrammetrically. Using the accuracy verification concept introduced in the first case study, the MMS data accuracy should be verified before it is used to verify the accuracy of any other dataset.

PennDOT staff surveyed 28 independent checkpoints along the two sides of the highway using traditional leveling techniques (**Figure 18**). These highly accurate checkpoints were used to verify the accuracy of the MMS data. **Table 5** lists the results, showing the vertical accuracy of the MMS data to be around 0.044 feet (0.013 m).

To compare the accuracy of the compiled DTM against the MMS data, elevations for the 28 checkpoints were derived from the MMS data (**Figure 18**). **Table 6** lists the results of these evaluations. It is evident that the UAS-based DTM had a vertical bias of around 0.224 feet. Once the bias is removed, the vertical accuracy of the UAS-based DTM was around 0.080 feet

PennDOT UAS Proof of Concept - Accuracy Analysis (Comparing MMS DTM to PennDOT new check points)

Note: Elevation of check points were re-projected to Geoid 12B to match the vertical datum of the data

Point ID	Surveyed Elevation			MMS Elevation	Residual Values (ft.)	Delta Z after Z-bias Removed (ft.)
	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Elevation (ft.)	Error in Elevation (ft.)	
CP_1	2447833.0894	321000.2444	1090.7890	1090.7900	-0.0010	-0.0014
CP_2	2447802.1717	321113.8212	1094.5240	1094.5600	-0.0360	-0.0364
CP_3	2447772.2693	321223.4371	1098.1050	1098.1300	-0.0250	-0.0254
CP_4	2447748.5271	321310.1031	1100.9470	1100.9800	-0.0330	-0.0334
CP_5	2447717.8919	321422.8742	1104.6990	1104.6900	0.0090	0.0086
CP_6	2447692.8522	321515.1178	1107.7650	1107.7600	0.0050	0.0046
CP_7	2447667.4935	321607.4306	1110.8140	1110.8400	-0.0260	-0.0264
CP_8	2447639.9596	321708.4858	1114.1970	1114.2000	-0.0030	-0.0034
CP_9	2447616.1907	321796.2994	1117.1080	1117.1100	-0.0020	-0.0024
CP_10	2447589.1547	321894.9876	1120.3930	1120.4200	-0.0270	-0.0274
CP_11	2447560.6492	321999.9689	1123.9770	1123.9900	-0.0130	-0.0134
CP_12	2447536.9992	322086.5782	1126.8480	1126.8800	-0.0320	-0.0324
CP_13	2447513.7209	322171.3742	1129.7440	1129.7500	-0.0060	-0.0064
CP_14	2447482.2446	322286.9030	1133.5990	1133.6000	-0.0010	-0.0014
CP_15	2447289.8486	322243.5513	1137.7390	1137.7300	0.0090	0.0086
CP_16	2447321.2590	322140.1606	1133.7420	1133.7500	-0.0080	-0.0084
CP_17	2447344.1892	322065.5780	1131.1530	1131.1800	-0.0270	-0.0274
CP_18	2447377.7205	321955.0422	1127.2000	1127.2200	-0.0200	-0.0204
CP_19	2447409.6357	321850.7671	1123.6010	1123.5200	0.0810	0.0806
CP_20	2447440.6037	321752.7325	1120.2160	1120.2100	0.0060	0.0056
CP_21	2447466.1464	321667.5136	1117.2100	1117.2600	-0.0500	-0.0504
CP_22	2447498.7418	321554.6298	1113.2700	1113.3100	-0.0400	-0.0404
CP_23	2447530.3931	321444.9524	1109.5140	1109.3400	0.1740	0.1736
CP_24	2447552.5875	321369.0845	1106.8410	1106.7800	0.0610	0.0606
CP_25	2447581.7572	321268.5857	1103.2270	1103.2500	-0.0230	-0.0234
CP_26	2447606.8815	321181.3414	1100.1830	1100.1500	0.0330	0.0326
CP_27	2447634.7895	321084.3153	1096.7430	1096.7200	0.0230	0.0226
CP_28	2447667.2819	320972.5669	1092.7720	1092.7900	-0.0180	-0.0184
				Number of Check Points	28	28
				Mean Error	0.000	0.000
				Standard Deviation (StDEV)	0.045	0.045
				Root Mean Squares Error ($RMSE_{x\ or\ y\ or\ z}$)	0.044	0.044
				NSSDA Vert Accuracy at 95% accuracy Level	0.086	
				NSSDA Vert Accuracy at 95% accuracy Level after z-bias removal	0.086	

Table 5: Accuracy of MMS DTM as verified using surveyed checkpoints.

(0.025 m). Such vertical bias is clearly seen in the profiles taken along the road (**Figure 19**).

Surveyed checkpoints

Table 7 lists the results of evaluating the UAS-based DTM using the independent checkpoints from PennDOT (**Figure 18**). Again, the surveyed checkpoints clearly verify the existence of the vertical bias in the UAS-based DTM as it was revealed by the MMS data. Once the bias is removed from the data, the vertical accuracy of the photogrammetric DTM was found to be around 0.095 feet (0.029 m), which is in a close agreement with the MMS verification method.

Once the vertical bias is removed from the data, the accuracy results from the MMS-derived checkpoints align with those from the field-surveyed checkpoints. This agreement is a clear indication that MMS data is as accurate as the field-surveyed checkpoints.

Vertical biases are common in lidar data and can be estimated and removed as long as accurate ground control points are available within the project areas. Different from random errors, biases are systematic errors of a mathematical nature that can be modeled and removed from the data with the help of ground control points.

Additional verifications were performed by comparing the photogrammetric DTM to the DTM derived from MMS data. Contours generated from both technologies align horizontally and vertically within few tenths of a foot (**Figure 20**).

Conclusions

As geospatial data quality and georeferencing are better defined and refined, fusing geospatial datasets derived from different sources becomes a routine

Point ID	MMS Elevation			UAS Elevation	Residual Values (ft.)	Delta Z after Z-bias Removed (ft.)
	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Elevation (ft.)	Error in Elevation (ft.)	
CP_1	2447813.6658	320999.2773	1091.2600	1091.0900	0.1700	-0.0539
CP_2	2447783.7307	321113.7985	1095.1700	1094.9800	0.1900	-0.0339
CP_3	2447759.1650	321215.2972	1098.4000	1098.1600	0.2400	0.0161
CP_4	2447733.0793	321308.6243	1101.5000	1101.2200	0.2800	0.0561
CP_5	2447700.7566	321419.0448	1105.1900	1104.8700	0.3200	0.0961
CP_6	2447674.8168	321511.8570	1108.2900	1107.9800	0.3100	0.0861
CP_7	2447653.6632	321604.4581	1111.2300	1110.8400	0.3900	0.1661
CP_8	2447626.2922	321705.3985	1114.6300	1114.3200	0.3100	0.0861
CP_9	2447596.3534	321793.1424	1117.7100	1117.3800	0.3300	0.1061
CP_10	2447571.4603	321890.3933	1120.9300	1120.8700	0.0600	-0.1639
CP_11	2447546.6611	321995.9759	1124.4200	1124.2700	0.1500	-0.0739
CP_12	2447526.5566	322083.3588	1127.2400	1126.9900	0.2500	0.0261
CP_13	2447500.2614	322166.6011	1130.1800	1129.9000	0.2800	0.0561
CP_14	2447466.4229	322281.2289	1134.0600	1133.8900	0.1700	-0.0539
CP_15	2447308.6649	322248.5215	1138.2900	1138.0900	0.2000	-0.0239
CP_16	2447344.7171	322148.4501	1134.5300	1134.3400	0.1900	-0.0339
CP_17	2447365.3790	322069.0943	1131.7300	1131.6100	0.1200	-0.1039
CP_18	2447397.6980	321961.4341	1127.9300	1127.8300	0.1000	-0.1239
CP_19	2447432.4695	321852.6548	1124.1800	1124.1000	0.0800	-0.1439
CP_20	2447461.1104	321756.1124	1120.7400	1120.4600	0.2800	0.0561
CP_21	2447488.2891	321668.7552	1117.6600	1117.3400	0.3200	0.0961
CP_22	2447517.8379	321559.0553	1113.8200	1113.6100	0.2100	-0.0139
CP_23	2447551.4267	321449.0224	1110.0300	1109.8300	0.2000	-0.0239
CP_24	2447574.2564	321367.1508	1107.0900	1106.8800	0.2100	-0.0139
CP_25	2447603.1840	321268.4371	1103.5500	1103.2900	0.2600	0.0361
CP_26	2447630.6428	321182.1303	1100.5800	1100.4300	0.1500	-0.0739
CP_27	2447658.1476	321084.4832	1097.1100	1096.9100	0.2000	-0.0239
CP_28	2447691.2635	320973.0090	1093.2200	1092.9200	0.3000	0.0761
				Number of Check Points	28	28
				Mean Error	0.224	0.000
				Standard Deviation (StDEV)	0.083	0.083
				Root Mean Squares Error ($RMSE_{x\ or\ y\ or\ z}$)	**0.238**	**0.081**
				NSSDA Vert Accuracy at 95% accuracy Level	**0.467**	
				NSSDA Vert Accuracy at 95% accuracy Level after z-bias removal	**0.159**	

Table 6: Vertical accuracy of UAS-based DTM as verified using MMS data.

matter. Users of geospatial data can reap the benefits of this reality. With demand for digital twins on the rise, geospatial data fusion is an ideal solution for providing seamless 3D models for projects and their surrounding areas.

The above case studies demonstrate successful attempts to fuse different geospatial data to produce new, hybrid geospatial products with more potential to serve engineering projects than any of the individual components used in producing the final product. Combining disparate data sources requires careful communication about the data sources and data. Users must be aware that the hybrid product may have multiple accuracy levels depending on the data sources used in

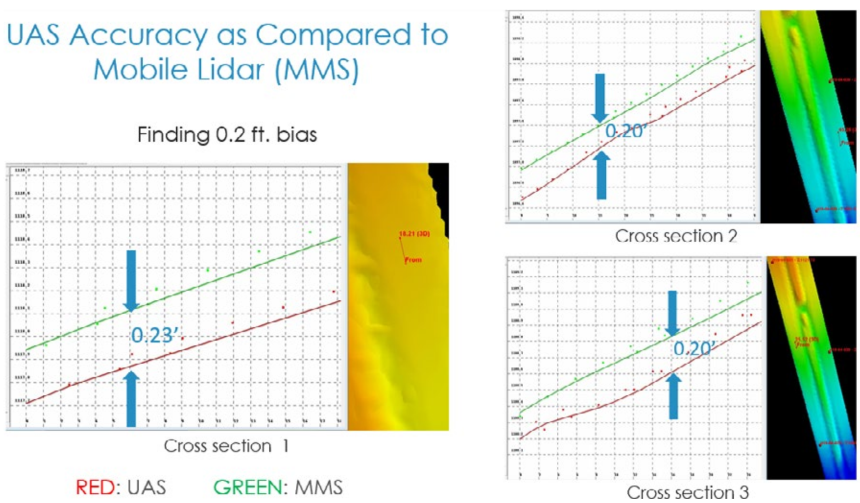


Figure 19: Bias in the photogrammetric DTM.

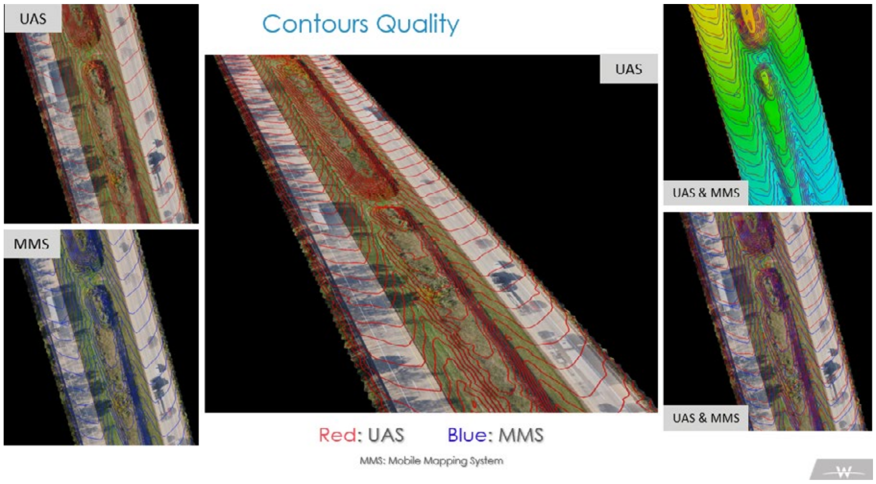


Figure 20: One-foot contours generated from MMS and stereo UAS imagery.

the generation of the new hybrid product. This can safely be accomplished through the metadata, which needs to be closely attached to the new product.

This new approach is far more economical than current practices, as it leverages existing data and enables effective utilization of UAS as an acquisition platform. Public-domain geospatial data is increasingly available from state and county GIS websites. It provides tremendous relief to project budgets and schedules, and in most cases can be obtained instantaneously and free of charge.

In addition, this research proved that stereo pairs from UAS-based imagery can be used to support design-grade surveys for road engineering, assuming the UAS mission is planned and executed properly. UAS can be used in permissible areas (off roads and away from populated areas according to FAA regulations) to provide cost-effective products and replace countless hours of labor-intensive field surveying.

Finally, emerging geospatial technologies such as UAS are effective in serving transportation projects to help reduce costs and expedite delivery schedules. Using different technologies to serve projects with diverse specifications and requirements is the most efficient way to execute transportation projects as the hybrid approach contributes to better efficiency and resource utilization. Accuracy on demand within a project is a logical outcome of the hybrid approach. ∎

PennDOT UAS Proof of Concept - Accuracy Analysis (Comparing UAS DTM to PennDOT new check points)

Note: Elevation of check points were re-projected to Geoid 12B to match the vertical datum of the data

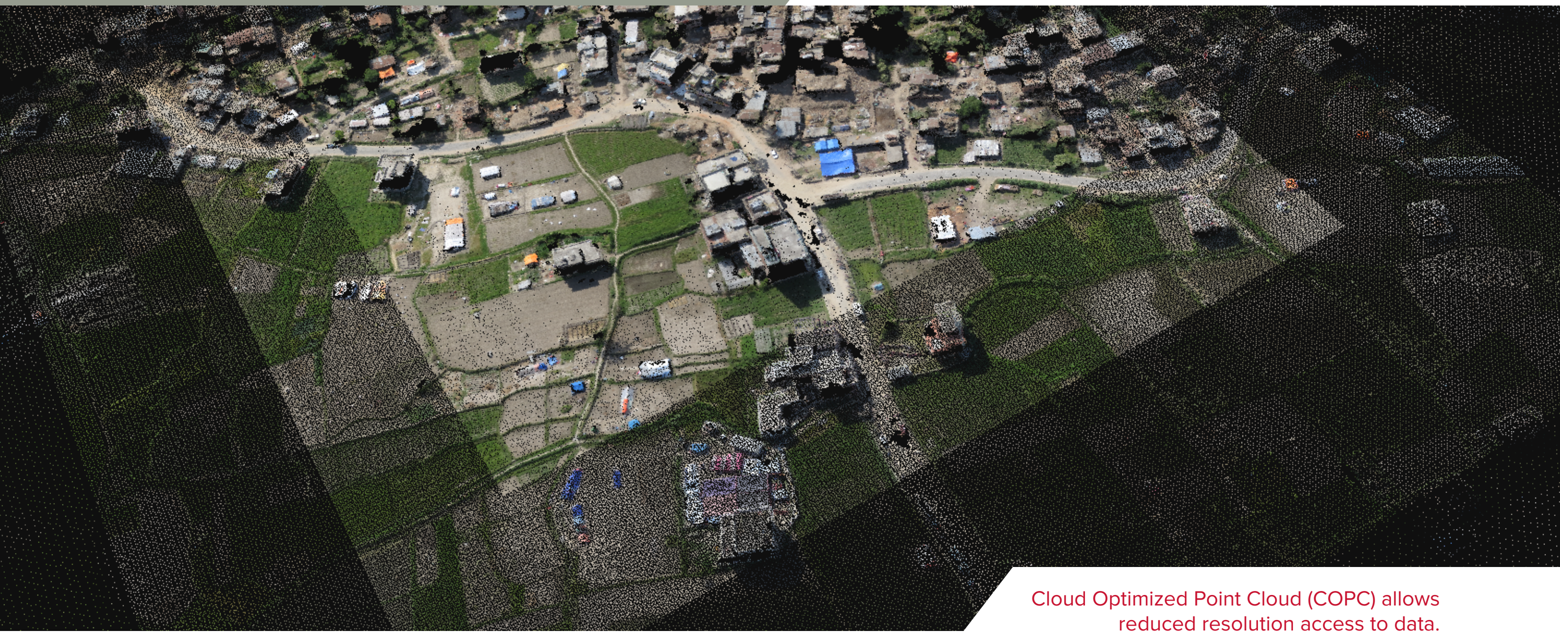
Point ID	Surveyed Elevation			UAS Elevation	Residual Values (ft.)	Delta Z after Z-bias Removed (ft.)
	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Elevation (ft.)	Error in Elevation (ft.)	
CP_1	2447833.0894	321000.2444	1090.7890	1090.6120	0.1770	-0.0216
CP_2	2447802.1717	321113.8212	1094.5240	1094.3850	0.1390	-0.0596
CP_3	2447772.2693	321223.4371	1098.1050	1097.9650	0.1400	-0.0586
CP_4	2447748.5271	321310.1031	1100.9470	1100.8140	0.1330	-0.0656
CP_5	2447717.8919	321422.8742	1104.6990	1104.4980	0.2010	0.0024
CP_6	2447692.8522	321515.1178	1107.7650	1107.5460	0.2190	0.0204
CP_7	2447667.4935	321607.4306	1110.8140	1110.6590	0.1550	-0.0436
CP_8	2447639.9596	321708.4858	1114.1970	1114.0610	0.1360	-0.0626
CP_9	2447616.1907	321796.2994	1117.1080	1116.8630	0.2450	0.0464
CP_10	2447589.1547	321894.9876	1120.3930	1120.2970	0.0960	-0.1026
CP_11	2447560.6492	321999.9689	1123.9770	1123.7690	0.2080	0.0094
CP_12	2447536.9992	322086.5782	1126.8480	1126.7280	0.1200	-0.0786
CP_13	2447513.7209	322171.3742	1129.7440	1129.6260	0.1180	-0.0806
CP_14	2447482.2446	322286.9030	1133.5990	1133.3060	0.2930	0.0944
CP_15	2447289.8486	322243.5513	1137.7390	1137.5200	0.2190	0.0204
CP_16	2447321.2590	322140.1606	1133.7420	1133.6600	0.0820	-0.1166
CP_17	2447344.1892	322065.5780	1131.1530	1130.9820	0.1710	-0.0276
CP_18	2447377.7205	321955.0422	1127.2000	1127.0130	0.1870	-0.0116
CP_19	2447409.6357	321850.7671	1123.6010	1123.6410	-0.0400	-0.2386
CP_20	2447440.6037	321752.7325	1120.2160	1119.9360	0.2800	0.0814
CP_21	2447466.1464	321667.5136	1117.2100	1116.8400	0.3700	0.1714
CP_22	2447498.7418	321554.6298	1113.2700	1112.9910	0.2790	0.0804
CP_23	2447530.3931	321444.9524	1109.5140	1109.3450	0.1690	-0.0296
CP_24	2447552.5875	321369.0845	1106.8410	1106.5450	0.2960	0.0974
CP_25	2447581.7572	321268.5857	1103.2270	1102.8890	0.3380	0.1394
CP_26	2447606.8815	321181.3414	1100.1830	1099.9710	0.2120	0.0134
CP_27	2447634.7895	321084.3153	1096.7430	1096.5550	0.1880	-0.0106
CP_28	2447667.2819	320972.5669	1092.7720	1092.3410	0.4310	0.2324
	Number of Check Points				28	28
	Mean Error				0.199	0.000
	Standard Deviation (StDEV)				0.096	0.096
	Root Mean Squares Error ($RMSE_{x\ or\ y\ or\ z}$)				**0.220**	**0.095**
	NSSDA Vert Accuracy at 95% accuracy Level				**0.431**	
	NSSDA Vert Accuracy at 95% accuracy Level after z-bias removal				**0.185**	

Table 7: UAS-based DTM vertical accuracy as verified using surveyed checkpoints.

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

Tom Ruschkewicz, Woolpert Practice Leader, Transportation, has 26 years of experience in the surveying and geospatial industry. A professional surveyor in four states, he has a diverse background encompassing public transportation, aviation, infrastructure, utilities, energy, telecommunications and residential/ commercial land development. He has managed projects across the United States providing land surveying, geodetic control networks, lidar, aerial photogrammetry, right-of-way acquisition, UAS missions, subsurface utility engineering and other geospatial services.


LEADING PROVIDER OF
LIDAR DATA
AND SOLUTIONS
WOOLPERT
ARCHITECTURE | ENGINEERING | GEOSPATIAL
woolpert.com/geospatial



Cloud Optimized Point Cloud (COPC) allows reduced resolution access to data.

Cloud Native Geospatial Lidar with the Cloud Optimized Point Cloud

Lidar consultancy offers efficacious access to big lidar datasets in the Cloud

BY HOWARD **BUTLER**

Most point-cloud processing tasks do not require all the data, but commonly used lidar formats require programs to read it all—whether over a network or directly from disk. In the case of compressed formats such as LAZ, reading it all means extra effort to decompress everything too. An ideal format is widely supported, is openly specified, and eliminates the need to read and decompress all the data for applications that desire only a spatial or reduced resolution subset.

The lidar domain to date has lacked a widely supported and openly specified data format with these features. Compression and geospatial metadata are well supported by the venerable LAZ format from Martin Isenburg, which builds on ASPRS LAS and has been available in the industry since 2012, but LAZ on its own has not supported allowing readers to perform spatial partitioning. The newly released Cloud Optimized Point Cloud (COPC) draft specification from Hobu, Inc. augments LAZ to provide these features in an opt-in way.

Cloud Native Geospatial, or CNG, is a term used to describe data organization and formats that support data extraction and processing from massive at-rest data archives in cloud object storage.

COPC is designed to assist lidar software developers in accessing large lidar data sets in the cloud.

Hobu, Inc., the creator of COPC, is an open-source software consultancy located in Iowa City, Iowa.

CNG requires mixing data format compression, indexing, and organization according to the constraints that cloud object storage imposes:

- Accessing information from the cloud is the same as accessing it from a disk, except many times slower
- Cloud formats work around this limitation by putting the pieces of data that applications want close to each other in the file, dramatically reducing the number of accesses required
- For spatial formats, the pieces of data applications want are usually close together in space, so "cloud formats" push together data in spatial clusters—tiles for imagery or small volumes for point clouds

A canonical example of a data format with these features in the geospatial raster data domain is the Cloud Optimized GeoTIFF (COG). COGs allow three things at once. First, the raster data is stored in the widely implemented and standard TIFF format. Second, geospatial metadata is provided using the standard GeoTIFF OGC specification. Third, the "cloud optimized" part organizes the data to allow software to incrementally access data with as little processing and access as possible when partitioning, filtering, or sampling across the data. These features allow raster users to opt-in to COG's capabilities as their software implements it rather than requiring an abrupt retooling or software development.

Two key features of LAZ enable this opt-in ability in the point-cloud domain with COPC. First, the LAZ format supports partial decompression by storing data in a series of data chunks. The second feature is the Variable Length Record (VLR) concept of LAS/LAZ, which can store application-specific support data of any kind. By combining LAZ chunking with VLRs that describe the octree structure, COPC allows data to be written in a LAZ file structured as a clustered octree. When data are then accessed according to the tree, software clients can fetch and decompress only what they need at the moment they need it.

The design approach means that clients that do not read the VLRs describing the COPC structure can still read all the LAZ content without impact. This crucial feature enables software to export COPC data and allows LAZ-reading software to consume it without providing special implementations of COPC software. As with COG, a COPC file is, in essence, "just an LAZ file".

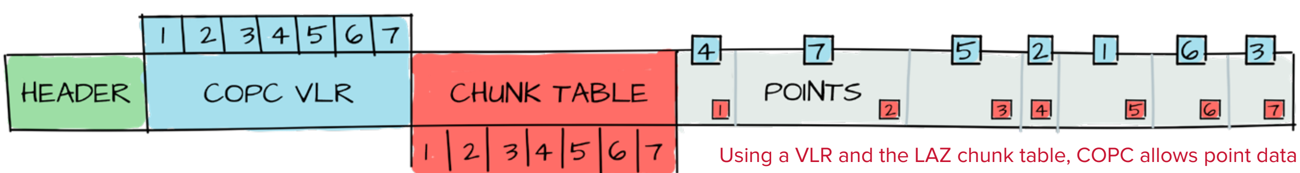
Kevin Murphy, developer of Applied Imagery's Quick Terrain Modeler, responded when asked about COPC as a format in the geospatial lidar ecosystem:

> *COPC offers explicit support at near-zero cost (in terms of storage or backwards compatibility) for many of the most challenging issues for indexing and management of large lidar data archives. With COPC it is trivial not just to seek[1] through file headers to find files of interest but to do the same within large files. If anything it reduces the need to pre-cut your data into digestible tiles, as you can quickly and easily do overviews and pull tiles or chips on-the-fly. And the best part is, none of your exploitation software needs to change. You can take advantage of the advanced organizational structure if you want, or just access it like any old LAZ and go to town.*

Software that reads LAZ already supports reading COPC point-cloud content, even if it cannot consume its organization. A data provider can deliver

continued on page 40

1 The word "seek" in computing parlance has the same meaning as skip, but it also means to skip in such a way so that the moving forward doesn't incur a cost—in our case it is direct i/o or reading of the file AND decompressing the bytes along the way.



Using a VLR and the LAZ chunk table, COPC allows point data to be stored as octree nodes that clients can directly seek to and decompress as needed.

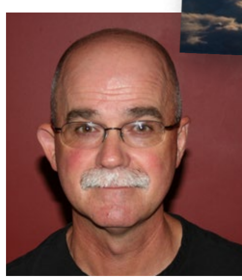
BY STEWART **WALKER**

The Essentials of SAR

Synthetic aperture radar (SAR) is an active sensing technology recognized as complementary to lidar. Many of us have struggled during our careers, however, with SAR textbooks in which the mathematics discouraged or intimidated us. *LIDAR Magazine* has covered SAR topics from time to time[1] and acknowledged its value for mapping and measurement tasks. Yet it's not as easy to understand as lidar and the plethora of physics concepts and the profusion of forbidding equations, often dripping with Fourier transforms and complex numbers, have rendered it somewhat inaccessible. Thus we accept the merits of the end-products and use them without fully comprehending how they were created or what can be derived from SAR data.

This book aims to fix that. Tom Ager is president of TomAger LLC, but for most of his career fulfilled a variety of duties as a research and development program manager at the National Geospatial-Intelligence Agency. As a one-person company he currently advises one of the SAR smallsat start-ups, ICEYE, and pursues his passion by teaching SAR to both government and private clients across the globe. So he was a spook, but this is barely evident in either the language or the examples in the book—and his vast experience shines brightly. The subtitle gives an insight: *A Conceptual View of Synthetic Aperture Radar and its Remarkable Capabilities*. Throughout the book, as he reveals the properties of SAR, he often stops to comment on just how astonishing these are. The book is enhanced by quotations from authors well beyond the world of SAR—often the classics or music—and I relished his choice to start the book, from Francis Bacon, "There is no excellent beauty, that hath not some strangeness in the proportion." This, therefore, is no ordinary SAR textbook.

Ager has grouped the 22 chapters into six "apertures", an affectation perhaps but certainly more engaging than "parts": the nature of SAR; the look of SAR images; an overview of SAR products; SAR and the geolocation revolution; SAR illumination and design considerations; imagining the future. Supporting material is printed on a blue background at the chapter ends and there are no less than 113 useful footnotes. There are equations, but they are straightforward and fastidiously explained.



THE ESSENTIALS OF SAR
THOMAS P. AGER

- TomAger LLC, Lewes, Delaware,
- 2021. 253 x 178 mm, xvi + 291 pp, 257 color and black and white illustrations, 4 tables, index.
- Paperback, ISBN 9798512864487, $50.00 Amazon.

The book is completed with three appendices—derivation of the antenna spacing constraint; measuring the ripples: how a SAR sensor records phase history data; how SAR processing improves the signal-to-noise ratio—and a list of symbols and acronyms. Although sources are formally cited throughout the book, there is no bibliography or suggestions for further reading. It would be contradictory, certainly, to recommend books for which Ager is pushing the cure!

1 See, for example: Walker, A.S., 2017. Changing the guard: addressing complementary technologies, *LIDAR Magazine*, 7(8): 12-19, December 2017; and Walker, S., 2020, Dr. Joerg Hermann: senior vice president, special projects, Capella Space, *LIDAR Magazine*, 10(1): 38-42, January/February 2020.

Ager guides the reader gently, explaining concepts in words, introducing technical terms only when necessary, and illuminates the path with a stream of simple, well designed graphics, presumably developed for his own teaching, together with excerpts from SAR images and derived products. The material is not oversimplified, however, and deriving maximum benefit from his efforts requires concentration, re-reading of sections and referring back to concepts, symbols and acronyms used earlier. Indeed, your reviewer plans to read the book, cover-to-cover, a second time! Ager's goal of rendering the technology comprehensible is unarguably met, yet along the way some formidable equations, for example for pulse repetition frequency and the signal-to-noise ratio, are derived in easy steps. Moreover, towards the end readers find themselves believing that they could say something intelligent during the design of an airborne or satellite SAR sensor.

The concepts are illustrated by examples from a wide variety of airborne and spaceborne SAR sources. A table of these, as an appendix, would be convenient and would, in the spirit of the book, be limited in scope, giving just launch dates, principal specifications and products, and country of origin. The danger, obviously, is that such information inevitably would quickly become outdated.

The Essentials of SAR is self-published and available on Amazon. It is pleasing to the eye and your reviewer found few errors or typos, although the author has indicated some minor improvements he would make if there were a second edition or reprint. Readers interested in SAR casually, professionally or scientifically, as well as consumers of SAR products who want to understand their purchases better, ought to buy this book. Ager has succeeded magnificently is his mission to explain SAR in terms that almost everyone can understand. He has given thought to a sequel–*LIDAR Magazine* would welcome it.

Stewart Walker, Managing Editor, *LIDAR Magazine*.

Butler, *continued from page 36*

COPC-organized content to clients, and those with updated software can leverage its advanced capabilities, while those without can continue to use the format as before. The incremental opt-in approach of COPC will enable software systems to catch up at their own pace while allowing the early adopters to take advantage.

A major feature of COPC that early adopters can leverage is the ability to "range read" the data they require when they need it over HTTP. Range read capability is a key feature of COG and it is necessary for incremental access over cloud-storage solutions such as Amazon S3 or Azure Blob Storage. Incremental access means that a browser-based visualization client or an adaptive-processing technique can pan through the data over the internet, over the local file system, or over cloud object storage and control the data access resolution and extent efficiently.

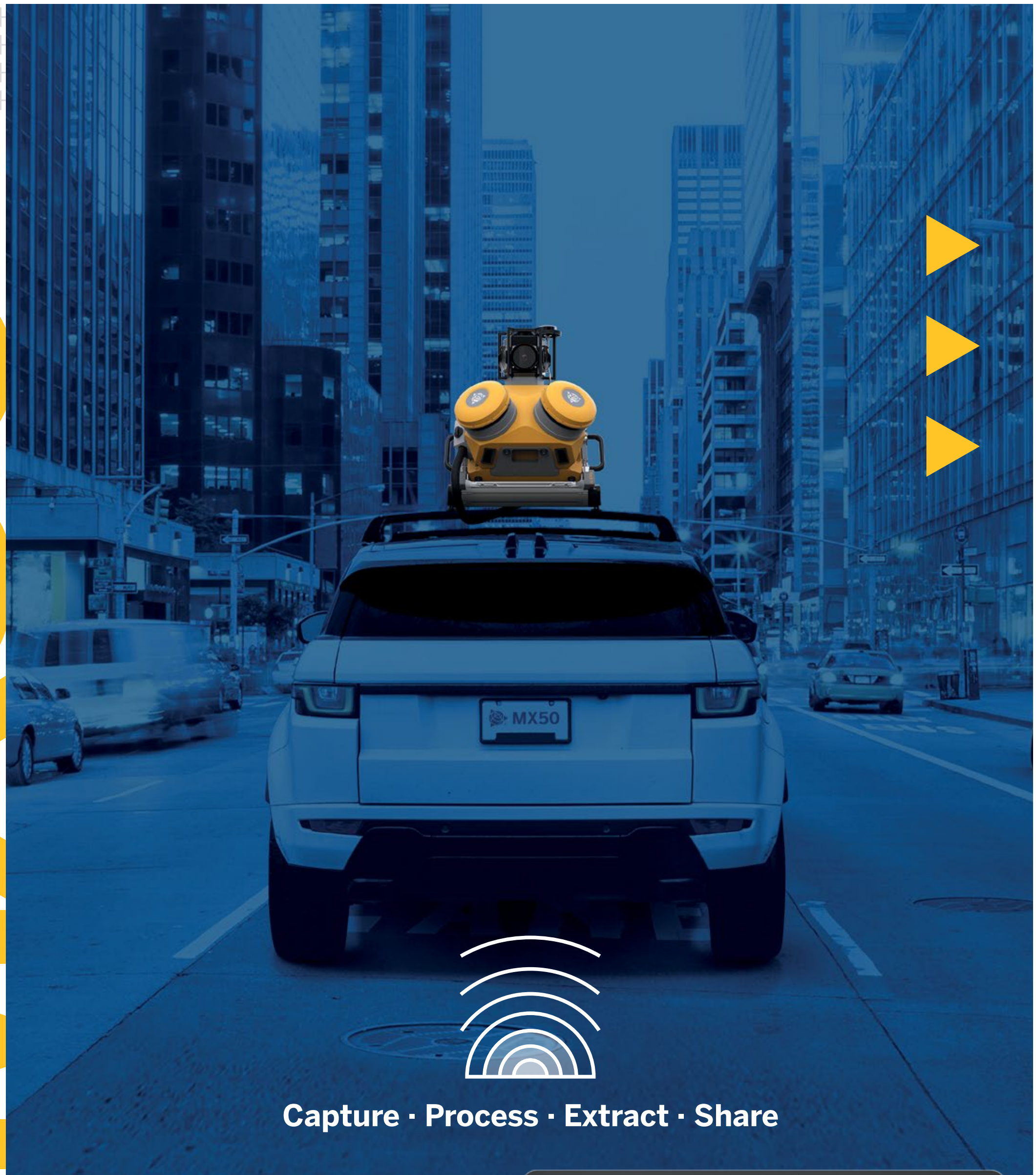
Proprietary point-cloud formats exist that provide some of COPC's features, especially those combining compressed storage with data organized as clustered octrees. None of them is openly specified, and none provides open-source software APIs to consume and produce them, however. Importantly, none of them is a valid delivery format that meets the USGS Lidar Base Specification.

The COPC specification is open source and available at copc.io. Open-source tooling such as Potree, PDAL, and Untwine are being updated to support reading and writing COPC data. Thus we hope that software vendors and data providers will see it as a useful enhancement to apply to LAZ data being delivered for tackling the large-scale data management and processing challenges that lidar data provides.

Howard Butler is the founder and president of Hobu, Inc., an open-source software consultancy located in Iowa City, Iowa. Hobu focuses on point-cloud data management solutions. He is an active participant in the ASPRS LAS Committee, a Project Steering Committee member of both the PROJ and GDAL projects, a contributing author to the GeoJSON specification, and a past member of the OSGeo Board of Directors. With his firm, Howard leads the development of the PDAL and Entwine open-source point-cloud processing and organization software libraries.

MOBILE MAPPING

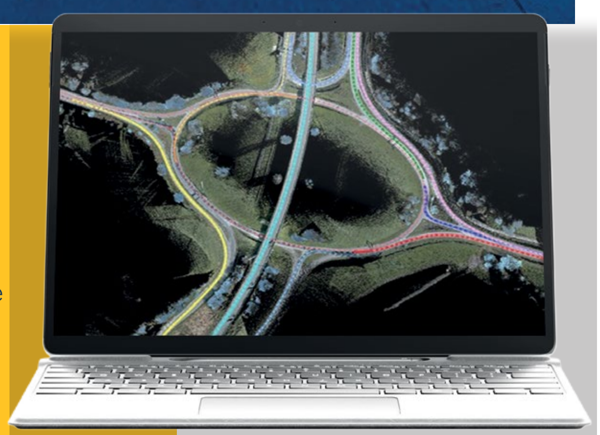
MX50



Take Productivity On The Road

Meet mobile mapping that's as simple as putting your foot on the gas. Powered by Trimble's own precise laser system and 360-degree panoramic camera,the **NEW TRIMBLE® MX50** handles data capturing, processing, and sharing seamlessly at top speed with the accuracy you demand. Slash work time while harnessing all the power of rich, reliable data you control yourself. Now you're ready to roll.

Geospatial.trimble.com/MX50



SEILER GEOSPATIAL

Trimble. Authorized Distribution Partner

www.seilergeo.com

DeepRoute on the Road to Making All Transportation Autonomous

Chinese integrator enjoys robotaxi success

BY VICTOR **WONG**

Since *LIDAR Magazine* spoke with DeepRoute VP Nianqiu Liu in July 2020[1], the company has deployed robotaxis in Wuhan and Shenzhen, and received a Drivered Autonomous Vehicle permit from the California Public Utilities Commission. After receiving a CES Innovation Award last year for its unique combination of software and sensing solutions, the company showcased its DeepRoute-Engine at CES 2021. DeepRoute is also a member of Nvidia's Inception Program. The company's research has resulted in a number of published papers, including

1 Walker, A.S., 2020. AV lidar needs software too, *LIDAR Magazine*, 10(5): 40-45, October/November 2020.

Robotaxi in the busy downtown of Shenzhen, Guangdong, China. The DeepRoute rooftop box is clearly visible

recent contributions on motion forecasting[2] and point-cloud segmentation[3].

DeepRoute has been testing autonomous vehicles on public roads since early 2019. In less than two years, road tests have taken place in Shenzhen, Wuhan, and Hangzhou, using Lincoln MKZ, Dongfeng E70, and Geely Geometry A. The testing in Wuhan is based on the RoboTaxi partnership with Dongfeng Motors, and the one in Hangzhou is based on the RoboTaxi partnership with Cao Cao Mobility, a ride-hailing company backed by Geely. The project in Shenzhen is DeepRoute's own. The different characteristics of the three cities bring diversity to the data, allowing us to advance our technology more efficiently.

This year DeepRoute-equipped robotaxis are operating in the busy downtown streets of Shenzhen and over 10,000 customer applications were received in one month to test the new technology. Citizens in Shenzhen, the Silicon Valley of China, are definitely curious and quick to embrace the new trend. During an outbreak of Covid-19 in June in Guangzhou province, DeepRoute.ai took the initiative to contact local government. DeepRoute dispatched robotaxis to deliver Covid-19 test samples to hospitals. The robotaxis were on standby 24/7 and delivered over 14,000 test samples per day. DeepRoute and the robotaxi operators are considering expanding the robotaxi fleet for daily operations to accommodate increasing interest. Thanks to recent Series B funding, DeepRoute aims to scale up its own fleet, as well as collaborating with automakers, to over 150 robotaxis in the coming months, operating in the central business district to make robotaxi service more accessible to the general public. Offering more robotaxis in the three cities would provide more case studies under complex road situations, thus increasing data efficiency.

> “Using machine learning and heuristic algorithms, the system can identify and predict the actions of surrounding objects in a range of 150 m.”

Originally there were separate suppliers for lidar, radar, cameras, GNSS receivers, IMUs, and the task of integrating these technologies would be left to vehicle manufacturers, but, as of

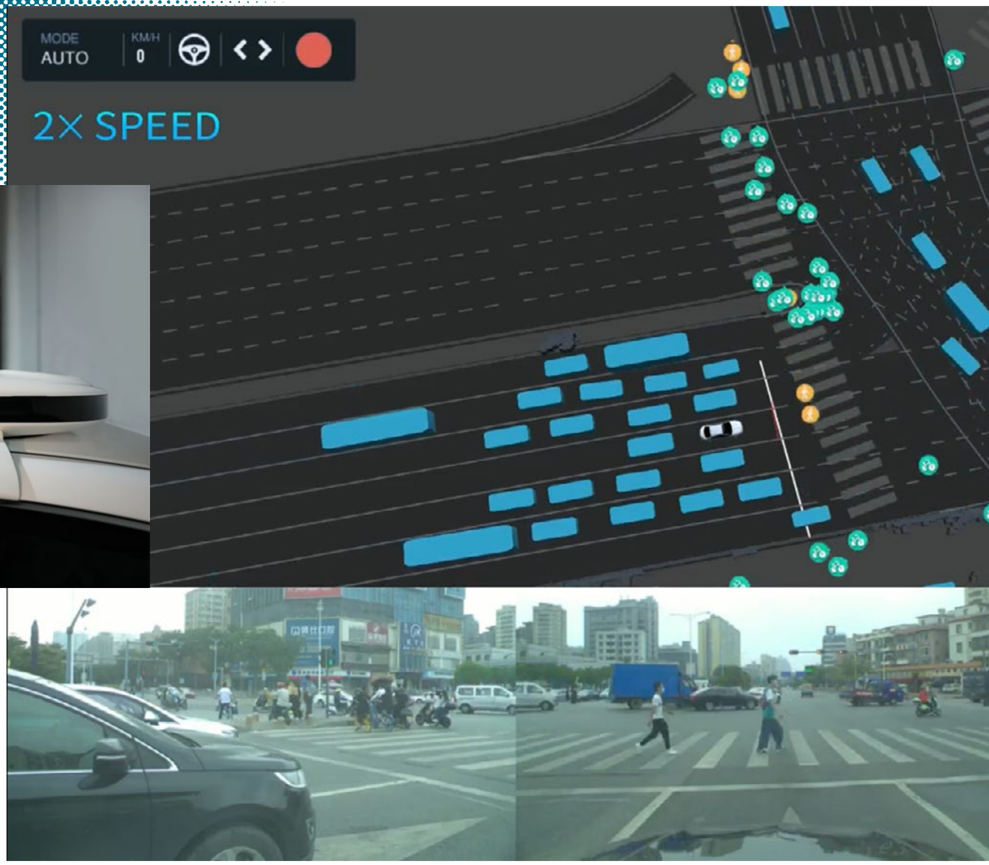
Robotaxi equipped with DeepRoute rooftop box ready to deliver covid-19 test samples in Shenzhen.

---

2 Ye, M., T. Cao and Q. Chen, 2021. TPCN: Temporal Point Cloud Networks for motion forecasting, CVPR 2021, 11318-11327.

3 Ye, M., S. Xu, T. Cao and Q. Chen, 2021. DRINet: a Dual-Representation Iterative Learning Network for point cloud segmentation, International Conference on Computer Vision (ICCV), 2021, 10 pp.

Close-up of rooftop box.



DeepRoute.ai visualizer showing robotaxi perception at crossroads in the Futian central business district, Shenzhen.

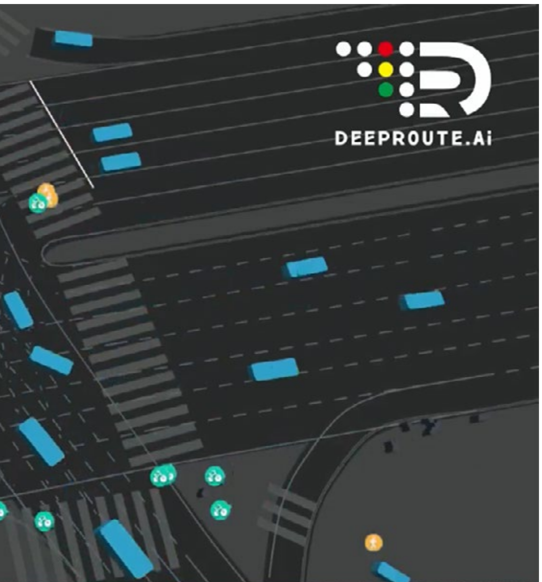
2021, DeepRoute has produced ready-to-go self-driving solutions that can be mounted on cars from many automakers.

DeepRoute, an international providers of full-stack, Level 4 self-driving solutions, is using its award-winning, innovative sensor technology to solve the engineering challenge of safe and affordable self-driving. Currently partnering with automotive OEMs, Tier 1 suppliers, mobility technology providers, and transportation and logistics companies, DeepRoute offers products and services that allow its clients to begin testing the self-driving technology on their vehicles immediately, and open up a wealth of opportunities for the future of transportation.

With the option to implement a full-stack solution, or individual modules such as high-accuracy perception, DeepRoute's highly customizable services allow for greater innovation in alternative forms of transportation moving forward. Depending on a client's requirements, DeepRoute can select and combine multiple brands of lidars, with the goals of optimizing performance and lowering costs.

DeepRoute's lidar tests measure a number of vital components, including frame rate, frequency, field of view, horizontal angular resolution, vertical angular resolution, ranging capability and accuracy, while DeepRoute's performance simulations test the stability, power consumption, and detection efficiency, to determine the best solution while maintaining affordability. DeepRoute currently tests and utilizes a number of brands, such as Hesai, Innoviz, Ouster, RoboSense and Velodyne.

The company's sensing solution, DeepRoute-Sense, includes a slim vehicle rooftop box and advanced sensor fusion calibration service. Only 9.6" high, the box contains seven vehicle cameras, three lidars, GNSS, among other sensors, and the corresponding telecommunications and data synchronization controllers. Using machine learning and heuristic algorithms, the system can identify and predict the actions of surrounding objects in a range of 150 m, while its vehicle camera, DeepRoute-Vision, allows for optimal detection performance while also avoiding overexposure. The highly precise system can reduce the impact of



DeepRoute-Tite, the compact vehicle computing platform, installed in the trunk of a robotaxi.

rain, fog, dust, and direct sunlight using automatic image adjustment and fine LED flicker-resistance, allowing vehicles to drive safely in extreme conditions.

Since its announcement of over one million miles driven in challenging city streets around the world without accidents[4], DeepRoute has further improved its algorithms and, indeed, the company has now topped two million kilometers. Deep learning plays an important role in its software development, providing key information for DeepRoute's planning and control modules. Inaccurate detections could lead to safety issues on the road, which is why the use of multiple sensors is critical. DeepRoute-Syntric, which is DeepRoute's data-synchronization device, can also monitor the status of hardware, sensors included, to command the vehicle to stop when not operating properly. Ranking highly on the KITTI and Semantic KITTI tests, DeepRoute's perception algorithm fuses the data before inference, which makes the detection result more reliable.

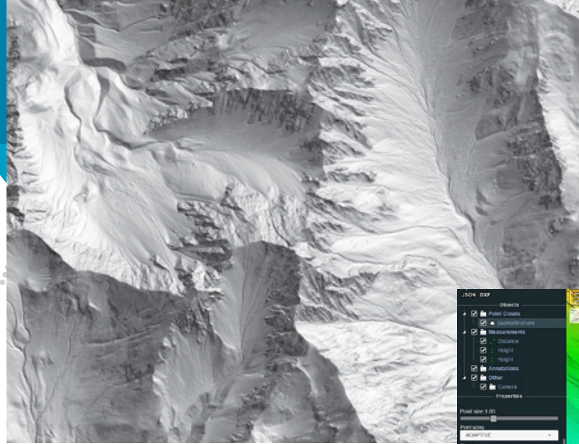
DeepRoute's independently developed inference engine minimizes the computing resources required, making it possible to lower the power consumption of computing platforms using different brands, such as AMD, Intel, and Nvidia. The data collected by the various sensors is calibrated using a controller, while DeepRoute-Syntric calibrates the time and space information. The company ultimately finds success in the connection of its range of sensors, in terms of both hardware, which entails the rooftop box, in-car components, and the associated cabling and wireless connections, and software.

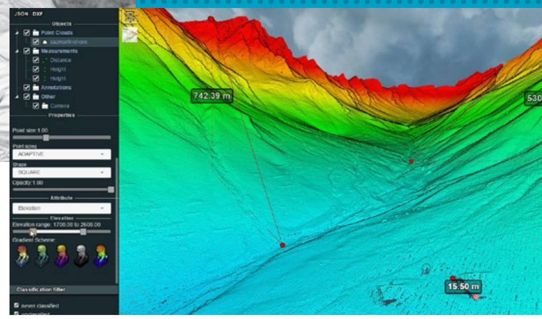
DeepRoute-Tite is a 100-watt computing platform that serves as the brain of the self-driving system. Utilizing a powerful inference engine and deep learning models, DeepRoute-Tite is extremely power-efficient, requiring only about 11% of traditional solutions' power consumption. It also minimizes the amount of computation required to output useful data, shortening decision-making time to offer a smooth ride experience. Additionally, its compact size also saves much room in the trunk.

DeepRoute, therefore, has established a reputation for innovation and the ability to use sensors from multiple providers. Its success in long-term trials suggests that the company will have a strong future.

Victor Wong is a hardware engineer at DeepRoute.ai's headquarters in Shenzhen, Guangdong, China.

4 https://www.globenewswire.com/en/news-release/2021/07/19/2264875/0/en/DeepRoute-ai-Level-4-Self-Driving-Technology-Innovation-Leader-Launches-Its-Robotaxi-Pilot-Program.html.





***Isenburg**, continued from page 48*
extraction (for mapmaking), visualization, and rasterization (to create high-resolution Digital Elevation Maps, aka DEMs). These operations are central to the field of Geographical Information Systems (GIS), which was and is a large industry. We detailed Martin's amazing streaming GIS toolchain in a paper in GIScience 2006."

Martin began working for Lawrence Livermore National Laboratory after his postdoc and PhD, but a mental illness episode upset his life and employment shortly after starting there. The result was that he ended up back in Germany with few prospects beyond the software libraries and techniques he pioneered. After some fits and starts, these formed the foundation of the LAStools software packages, and the Rapidlasso company he built to distribute them.

In spring 2011, Martin worked with Hobu, Inc. to enhance his LASzip point-cloud compression encoder and more formally apply it to ASPRS LAS data. This included adding support for all the LAS content types, adding chunking support, and refactoring it to use a typical arithmetic encoding approach. It was then released as open-source software (at laszip.org), and clients were able to use it with libLAS and LAStools to compress heavy lidar data. LASzip and LAZ continue to have a lasting impact on the commercial software that picked them up and are incorporated throughout the industry.

In 2010 through 2012, Martin actively supported the ASPRS LAS committee developing its new LAS 1.4 format. Features Martin championed include portions of the specification that describe "extra bytes" variable length records, preservation of pre-1.4 content organization, simplification of data organization, and continued advocacy for fixed-precision coordinate content to make the LAS specification easier for software implementers. A few years later, Martin released a complementary LASzip encoding technique for LAS 1.4 content with support from NOAA and the USGS, which was widely used as the archive and transmission format for national-scale lidar holdings throughout the world.

Throughout the 2010s, Martin grew his software company, Rapidlasso GmbH, by adding new features to the software and frequently traveling to places such as Indonesia, Philippines, Central America, and Europe to give workshops showing users how to leverage LAStools. Martin loved international travel, experiencing many cultures, and riding his paddle board in their surf zones. Proud to have never owned a car, Martin sought ecologically sound solutions and lived frugally to do his best to limit his impact on the planet's resources.

As others have noted in their memorials[134], Martin was a vocal advocate for the release of public scan data. He frequently gifted his software tools to groups through the "LASMoons" program to allow students and organizations to use LAStools to achieve specific academic and ecological lidar data processing tasks[5]. Not only did this program show users how to use the software effectively, it demonstrated the worldwide thirst for lidar data acquisition, processing, and compression.

3 blog.qgis.org/2021/09/14/in-memory-of-martin-isenburg/
4 geoweeknews.com/blogs/remembering-martin-isenburg-1972-2021
5 rapidlasso.com/category/lasmoons/

The open source part of LAStools will live on at github.com/LAStools/LAStools and lastools.osgeo.org. The commercial tools of Rapidlasso are planned to be licensed using the same mechanism. The new website is under construction and can be found at www.rapidlasso.de. Commercial customers with immediate license renewal inquiries are encouraged to email license@rapidlasso.de. Access to some operational material of the business is still disjointed, so please be patient as the work on reestablishing the licensing and service is still in progress.

The isolation, anxiety, and ambiguity of the pandemic has impacted nearly everyone. Unfortunately, for one of the lidar industry's prolific gadflies, that pressure became too much. The industry will miss the playful lidar guy with the speedy and quirky software that has done and will continue to do a ton of heavy lifting for grateful industry. Godspeed, Martin.

Howard Butler is the founder and president of Hobu, Inc., an open-source software consultancy located in Iowa City, Iowa. Hobu focuses on point-cloud data management solutions. He is an active participant in the ASPRS LAS Committee, a Project Steering Committee member of both the PROJ and GDAL projects, a contributing author to the GeoJSON specification, and a past member of the OSGeo Board of Directors. With his firm, Howard leads the development of the PDAL and Entwine open-source point-cloud processing and organization software libraries.

IN MEMORIAM: Martin Isenburg, 1972–2021

Lidar visionary and activist passes unexpectedly

Dr. Martin Isenburg, 49, of Rodgau, Germany, committed suicide at his vacation home in Sámara, Costa Rica about September 9, 2021, after a lifelong struggle with mental health which was exacerbated by the pandemic. Dr. Isenburg was the creator of the widely used LAStools, LASzip, and PulseWaves software packages, and he operated Rapidlasso GmbH while providing commercial and open-source software for lidar data processing, exploitation, compression, and organization.

Martin was born in Weiskirchen, Germany on July 6, 1972. After high school and a year of travel in Asia, he attended the Technical University of Darmstadt, where he studied computer science. An undergraduate visit to the University of British Columbia encouraged him to complete his MSc degree before following his mentor Jack Snoeyink from UBC to the University of North Carolina Chapel Hill. Working to complete his PhD at UNC, Martin continued research started at UBC into mesh compression techniques and, with funding from Hurricane Floyd efforts to develop new elevation models for North Carolina, he began to apply these techniques to processing lidar data.

A frequent presenter at meetings such as SIGGRAPH, Martin published and presented frequently on mesh handling and compression techniques in the computational geometry field throughout the 2000s. After UNC, he undertook a postdoc with Jonathan Shewchuck of University of California Berkeley to implement the "streaming delaunay" capability, which became a foundational technique of commercial LAStools such as blast2dem. By constructing out-of-core techniques for processing large geometry data collections, Martin was able to demonstrate memory-efficient tools to chew through the oncoming rush of lidar data captures beginning to appear for natural science and morphological uses.

> "His tools were easy to use; they worked and scaled; and they drove standards and became the foundation of countless lidar processing workflows."[1]

1 opentopography.org/blog/remembering-martin-isenburg-friend-and-inspiration-opentopography

His advisor, Jonathan Shewchuck, notes in his memorial to Martin[2]:

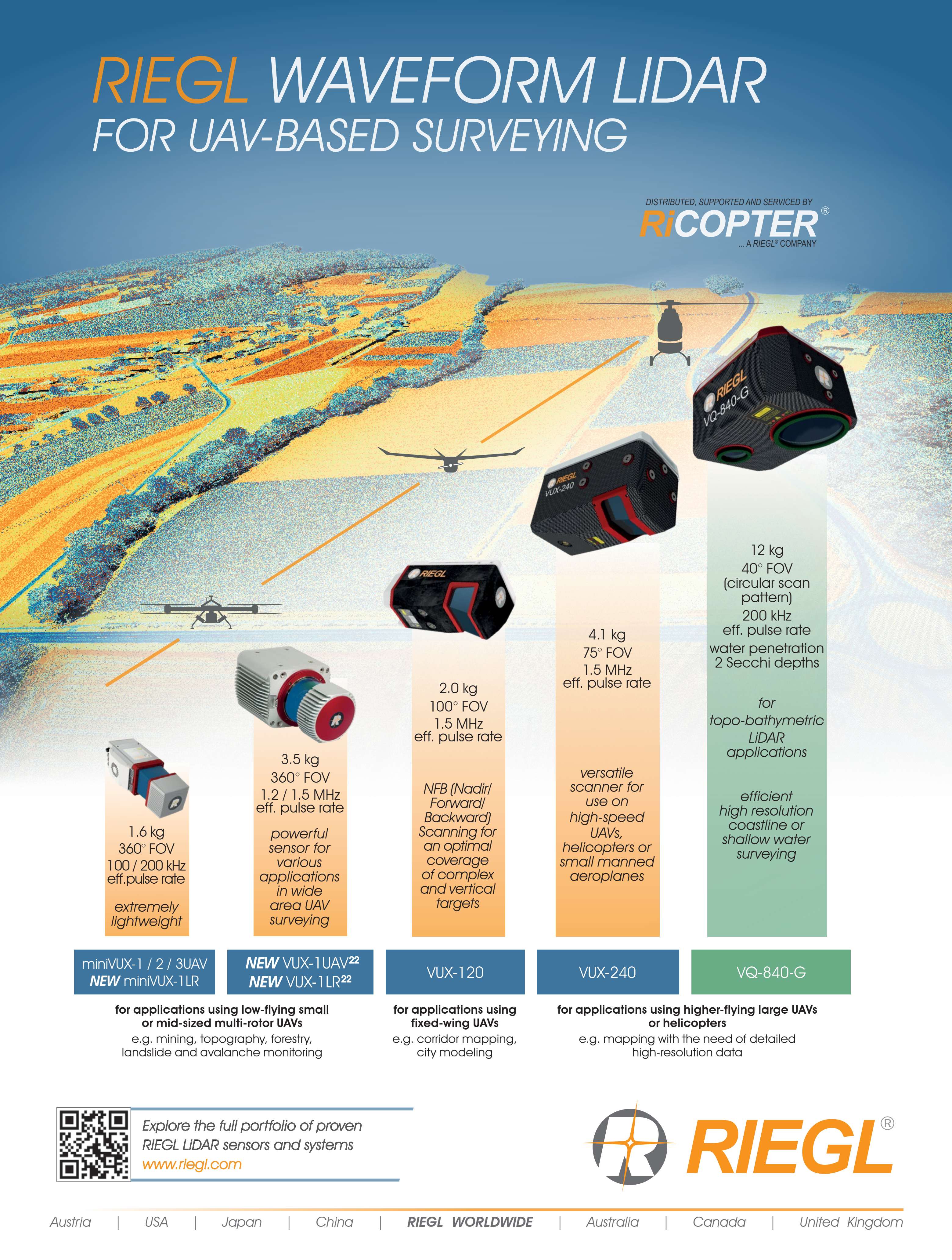
"I had the good fortune to work with Martin during what was probably the high point of his career and life. Martin was extremely energetic, productive, and creative throughout his two years at Berkeley. Before, during, and after that time, he pioneered ideas and software for streaming geometry processing, which have become standard methods for handling huge geometric data sets on commodity computers (like your laptop). 'Huge' meant hundreds of gigabytes in 2006, and means many terabytes today. His papers and software included algorithms for streaming mesh compression and decompression, mesh simplification, interpolation, isoline

2 people.eecs.berkeley.edu/~jrs/martin/

continued on page 46

BY HOWARD **BUTLER**


BUILD THE FUTURE
Discover the new Mapper UAV LiDAR solution by YellowScan.
yellowscan-lidar.com
FR: +33 411 931 400
US: +1 (801) 876-1007
YellowScan


RIEGL WAVEFORM LIDAR
FOR UAV-BASED SURVEYING
DISTRIBUTED, SUPPORTED AND SERVICED BY
RiCOPTER®
... A RIEGL® COMPANY
RIEGL
VQ-840-G
VUX-240
12 kg
40° FOV
(circular scan pattern)
200 kHz
eff. pulse rate
water penetration
2 Secchi depths
for topo-bathymetric LiDAR applications
efficient high resolution coastline or shallow water surveying
4.1 kg
75° FOV
1.5 MHz
eff. pulse rate
versatile scanner for use on high-speed UAVs, helicopters or small manned aeroplanes
2.0 kg
100° FOV
1.5 MHz
eff. pulse rate
NFB (Nadir/ Forward/ Backward) Scanning for an optimal coverage of complex and vertical targets
3.5 kg
360° FOV
1.2 / 1.5 MHz
eff. pulse rate
powerful sensor for various applications in wide area UAV surveying
1.6 kg
360° FOV
100 / 200 kHz
eff.pulse rate
extremely lightweight
miniVUX-1 / 2 / 3UAV
NEW miniVUX-1LR
NEW VUX-1UAV22
NEW VUX-1LR22
VUX-120
VUX-240
VQ-840-G
for applications using low-flying small or mid-sized multi-rotor UAVs
e.g. mining, topography, forestry, landslide and avalanche monitoring
for applications using fixed-wing UAVs
e.g. corridor mapping, city modeling
for applications using higher-flying large UAVs or helicopters
e.g. mapping with the need of detailed high-resolution data
Explore the full portfolio of proven RIEGL LIDAR sensors and systems
www.riegl.com
RIEGL®
Austria | USA | Japan | China | RIEGL WORLDWIDE | Australia | Canada | United Kingdom