LIDAR MAGAZINE

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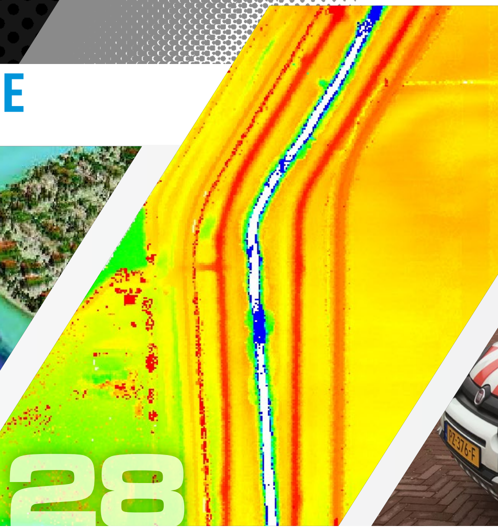
STEERING SINGLE PHOTON

LIDAR MAGAZINE



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◀ ON THE COVER

Geomatics industry veteran Ron Roth, Product Manager for Airborne Topographic Lidar, Hexagon Geosystems.

Photographed June 2018 in Lanham, Maryland.
Shirt and jacket courtesy of Armani.

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DR. A. STEWART WALKER

Summer Learning

I'm writing this at home in the hinge of a diptych of learning opportunities. I've just returned from the AEC Next/SPAR 3D conference in Anaheim, California. Organized by Diversified Communications, this is another combination of two conferences that have existed separately for many years. SPAR 3D dates from 2003, so this was the 16th in the series. AEC, however, dates back 40 years, with events both in the US and overseas. The relationship with Diversified Communications began 18 months ago, resulting in the renaming to AEC Next in 2017. The total attendance was nearly 2000 and there was a lively exhibition.

There were far too many high quality presentations to mention here, so we look forward to the proceedings and I hope to persuade some presenters to author articles in *LIDAR Magazine*. If there was a theme to help us discern a direction for the future, it was "an era of convergences". Technology continues to delight us with its development and exuberance, for example terrestrial and mobile lidar systems are lighter, cheaper and faster, and new platforms such as drones are well accepted. Meanwhile software improves apace and visualization, including AR/VR, does justice to the excellent data. In these pages I've often underlined the complementarity of technologies and SPAR 3D reinforced this message. Indeed, an unrelated example from a book I am reviewing for *PE&RS* springs to mind. The author mentions several times that the extraction of vegetation information from hyperspectral imagery is much improved if lidar and photogrammetry are brought into play[1].

Two keynotes, one on the design and construction of NVIDIA's new headquarters in Santa Clara, California, by presenters from NVIDIA and international architectural firm Gensler, and one on integrated project management, brought home to me that, however wonderful are the measurement technologies at our disposal, the reality of creating and constructing a modern building is daunting, the domain surely of especially imaginative, talented and persistent individuals and their teams.

Listening to a presentation, in a parallel session on autonomous technologies, by Quanergy CEO Dr. Louay Eldad, I was reminded that automotive lidar, consisting of firms aspiring to provide large numbers of small systems at economical prices for vehicles to run with varying degrees of autonomy, will increasingly influence traditional geospatial lidar, with its expensive, specialist systems sold in more modest quantities. If I were better organized, I would have known this long, long ago from the 2016 bumper holiday issue of *The Economist*[2]. This delay—not opening it till May 2018—is not born of some Calvinist delight in delayed gratification, but of burying the issue beneath a pile of other unread material. At that time the race was on to miniaturize

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lidar and suppliers were beginning to ship units to car manufacturers or automotive-component suppliers, using either solid-state or MEMS-based approaches. Next month I am visiting May Mobility in Ann Arbor, Michigan, to find out how they are deploying Cepton Technologies lidar on their autonomous vehicles.

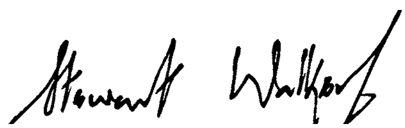
An entirely different application of lidar to cars enthralled the audience in a parallel session on digital historic preservation. Australia is home to the only surviving 1914 Delage Type-S grand prix car. After the engine of this unique vehicle failed, it was scanned inside and out—a task that involved considerable challenges on its own—and the results were used to create molds by 3D printing, from which a new engine was cast in a foundry. It worked and the presentation ended with a video clip showing the car back on the road!

This week I am bound for Las Vegas to attend HxGN LIVE 2018! This is the annual user conference of Hexagon, the Swedish conglomerate that has acquired Intergraph, Leica Geosystems and numerous other geospatial companies. It should attract several thousand participants. This is a far cry from the first user group meeting I organized—the Kern DSR UK user group meeting in York, England in December 1987, with perhaps 20 attendees. During the week, I hope to make progress on several articles in the pipeline about Hexagon—the history of its linear-mode lidar, the dawn of single-photon lidar, the marvels of spaceborne lidar and the strategies behind geospatial content programs. The highlights, however, will not be these articles but what we hear from the podium and see amongst the exhibits: without doubt there will be product introductions, significant incremental developments and innumerable, remarkable applications. More on this in the next issue!

I was reminded that it is some time since I reported encountering a particularly interesting piece while scanning my archive. I came across a paper by Peter Mott, a director of the UK company Hunting Surveys, "The use of radar altimetry in the mapping of a reservoir". The document has no further information on its provenance. The background was a project Huntings was awarded to generate 1:50,000 mapping with 20-foot contours of an area of 1500 square miles around the river Niger, deliverables due February 1960. The aerial photography was flown from 20,500 feet in the Fall of 1959 and airborne profile recorder lines along the sidelaps between the strips of photography were flown at between 5000 and 10,000 feet. The reduction in the labor hours to provide ground control in Z was 78%. The $RMSE_Z$ of the APR points was around 4 feet, but increased rapidly with flying height. The paper is very detailed and makes for fascinating reading. Why does this matter? As I've said before in these editorial pages, we must not forget the absolutely incredibly progress made in our subject—compare what was achieved in 1959, using an active radar sensor and flown without GNSS or IMU, which had not been invented yet, with the performance of the sensors discussed by authors in this issue. After the title page of the article is a full-page illustration of Hunting's DC-3 aircraft: note that the Basler BT-67 flown for Woolpert for their post-hurricane lidar analysis, described in this issue, is a much updated derivative of that very aircraft!

Other than playing bridge, few activities take my mind off matters geospatial more effectively than assembling IKEA furniture, with which I have populated homes in several countries since the late 1980s. Readers will have noticed that a robot has been developed by Nanyang Technological University in Singapore, capable of assembling an IKEA chair. It has two arms, both with cameras and force sensors, but does it use lidar?

Let me end on a lighter note. Much as I enjoy bringing you gems from *The Economist*—or from the past—that impinge on what we do, I would relish being able to bring you more from the world of fiction. Lidar folk figure rather infrequently in that medium, sad to say, but for this issue I happened on something that is at least reasonably close. *Last Stories* is a collection of short stories by the acclaimed Irish novelist William Trevor (numerous awards and five Man Booker nominations), published posthumously this year[3]. In one of the stories, a cartographer is reunited with a former student; the two fall in love, but it doesn't turn out well, the usual course for passion in the fictional north of England…



A. Stewart Walker // Managing Editor

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BY MIKE SHILLENN

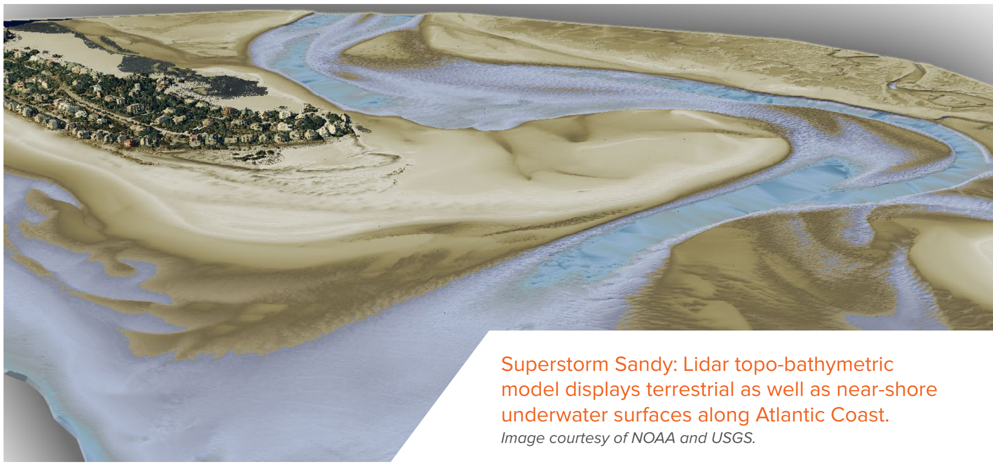
Interested in Lidar Surveys?

Now's the Time to Start Planning for 3DEP Grant Applications

Hurricanes, flooding, landslides, wildfires and erupting volcanoes—rarely a week goes by when you don't see headlines about these types of natural disasters, which result in untimely deaths and billions of dollars of damages to personal property. But what if we could better understand our geography and use that information to prevent or mitigate potential problems?

The technology to do that exists, and it's called light detection and ranging, or lidar. This cutting-edge survey technology uses lasers to scan the earth, collecting high-definition surface information in 3D. Not only does lidar enable users to pinpoint key features, it also helps reveal critical information relating to both the natural and built environments.

There is a seemingly endless potential for the use of lidar, and the key is finding a way to collect the data and make it readily available to all those who need it or could benefit from it. For many small agencies or individual organizations, lidar surveys can be cost prohibitive, no matter how valuable the resulting insights. That's where programs such as the United States Geological Survey (USGS) 3D Elevation Program (3DEP) come in.



Superstorm Sandy: Lidar topo-bathymetric model displays terrestrial as well as near-shore underwater surfaces along Atlantic Coast.
Image courtesy of NOAA and USGS.

What is 3DEP?

Now in its fifth year, the 3DEP initiative was developed in response to the growing needs for high quality topographic data and a wide range of other three-dimensional representations of the Nation's natural and constructed features. The primary goal is to systematically collect enhanced elevation data in the form of high-quality lidar for the conterminous United States, Hawaii, and the U.S. territories, over an 8-year period.

Each year, partnership proposals are accepted through the Broad Agency Announcement (BAA), providing federal matching funds to help finance large-area lidar collections which benefit multi-agency groups with common geospatial needs. This helps individual agencies minimize the costs while also improving the impact of the data collected. Over the last five years, this program has contributed more than $27 million in partnership funds, covering approximately one-third of the cost of acquiring 175,000 square miles of new lidar data for some 18 projects across 22 states.

Lidar data collected as part of 3DEP is valuable to a number of disciplines, including water resource planning, natural resource conservation, precision agriculture, geologic hazard mapping, wildlife management, mineral deposit sourcing, transportation, urban planning, and infrastructure management.

Already we've seen the value of lidar data and analytics applied in real-world scenarios.

Oso landslide

Following this tragic landslide, which resulted in 42 deaths, officials began conducting lidar surveys across the State of Washington. Using the data collected, geologists have been able to perform analyses and risk modeling to identify landslide deposits and hazard zones, bringing attention to areas where there is potential for landslide activity that could adversely impact infrastructure or public safety.


This point cloud was generated using the Pixels-To-Points™ tool and 192 overlapping drone-collected images.
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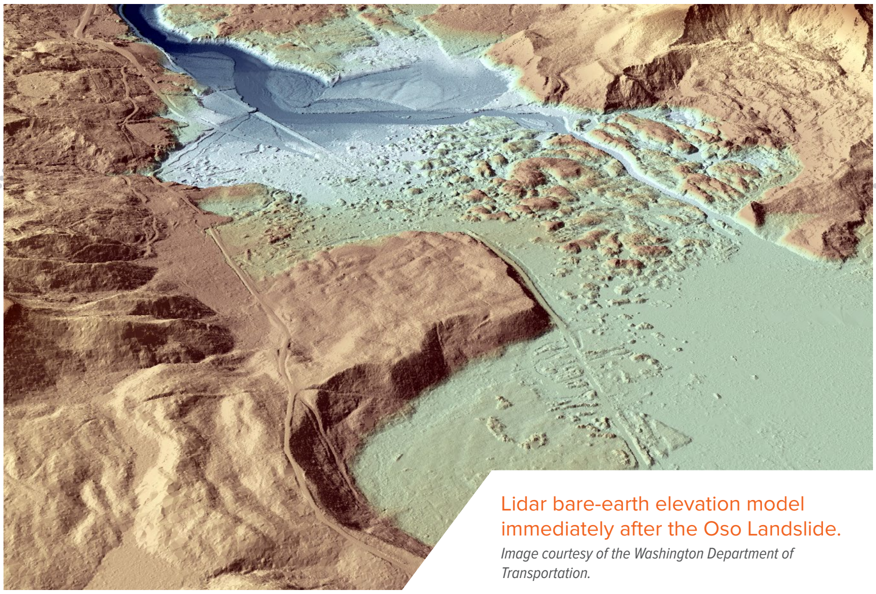
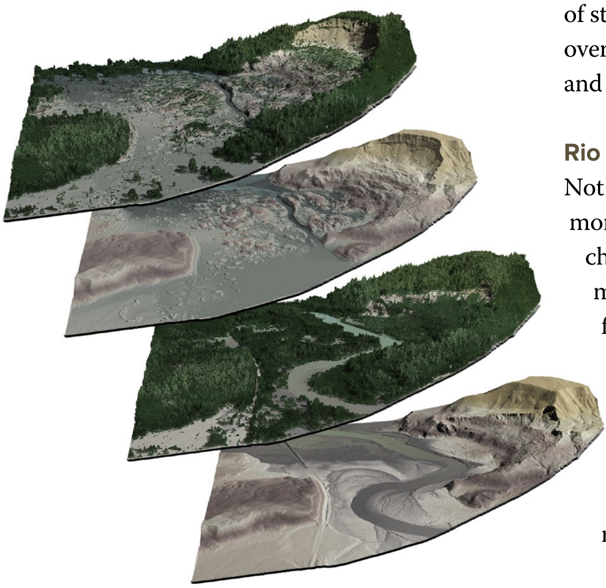
Hurricane Sandy

After one of the deadliest and most destructive events of the 2012 Atlantic hurricane season, high-resolution topographic and bathymetric elevation data was collected using lidar technology along the eastern seaboard from South Carolina to Rhode Island. The insights gained from this survey are assisting with hurricane recovery and rebuilding activities; assessments of shoreline vulnerability to coastal change hazards, such as severe storms, sea-level rise, and shoreline erosion and retreat; validation of storm-surge inundation predictions over urban areas; and watershed planning and resource management.



Lidar bare-earth elevation model immediately after the Oso Landslide. *Image courtesy of the Washington Department of Transportation.*



Rio Grande flooding

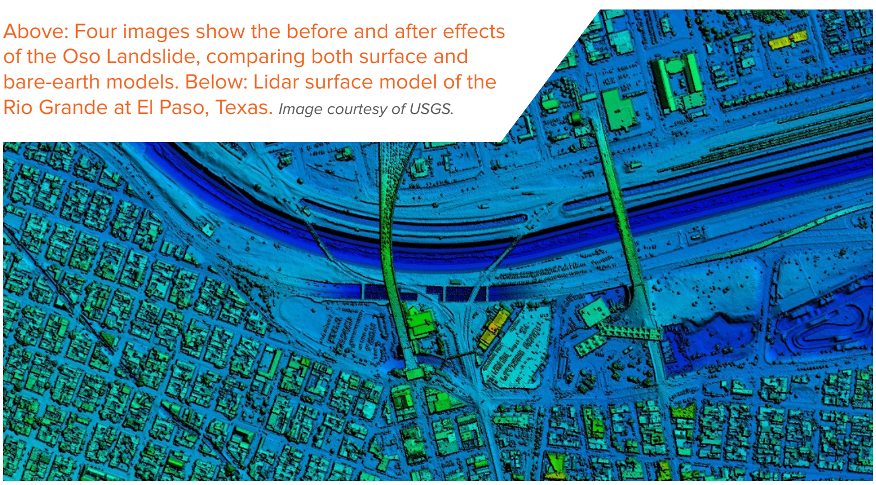
Not only is flooding one of the most common and costly disasters, flood risk can change over time as a result of development, weather patterns and other factors. A 3D lidar surface model was created for the City of El Paso, Texas, to identify areas at risk of flooding and support planning and outreach to communities in order to help them take action to reduce or mitigate flood risk.

How can my organization get involved with the 3DEP program?

The projects detailed above represent only a few of the ways lidar can be used. If you have a project in mind, it's time to start preparing now. The central tenet of 3DEP projects involves creating a coalition of stakeholders. With that in mind, you'll want to begin reaching out to others interested in collecting lidar data in your region and discuss the potential project scope.

The first official step for fiscal year 2018 3DEP will take place in early August when USGS issues its BAA, the competitive grant application. USGS offers background information on the BAA process through webinars and in-state presentations, details of which are at nationalmap.gov/3DEP/3dep_about.html.

Above: Four images show the before and after effects of the Oso Landslide, comparing both surface and bare-earth models. Below: Lidar surface model of the Rio Grande at El Paso, Texas. *Image courtesy of USGS.*



Michael Shillenn has more than 30 years of experience in the design, management and execution of photogrammetric mapping, lidar, GIS, and data conversion projects for a broad range of customers and end user applications. He has been granted the title of Certified Photogrammetrist by ASPRS. He is currently serving as vice president and program manager working from Quantum Spatial's West Chester, Pennsylvania office supporting the USGS, as well as other key federal, state, and local customers.

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harrisgeospatial.com/lidar

Leica Geosystems, Matterport Partner to Combine Digital Reality, Immersive Media

Norcross, Ga./Sunnyvale, Calif., 13 June 2018—Leica Geosystems, part of Hexagon, industry leader in measurement technology, and Matterport, an immersive 3D media technology company, today announced the availability of a reality capture solution for the real estate and Architecture, Engineering and Construction (AEC) markets.

Leica Geosystems redefined the imaging laser scanner market with the launch of the Leica BLK360, the world's smallest and most powerful portable 3D imaging laser scanner. The Matterport media platform makes it easy for anyone to create immersive 3D and digital reality versions of real-world spaces for the web, mobile and tablet devices, and VR headsets.

The integration between the Leica Geosystems BLK360 and the Matterport platform is relevant to a wide variety of industries, especially in the residential and commercial real estate as well as AEC markets. For example, in commercial real estate you can engage decision makers and add critical value to the buying/leasing process with dimensionally accurate 3D walkthroughs.

Reality capture simplified

Through the power of the BLK360 and the Matterport reality capture and cloud platform, capture has become a simplified process where spaces can be digitised with just the touch of a single button. The interoperability of the BLK360 and Matterport's reality capture platform provides users an easy-to-use solution that can be used by anyone, anywhere, bringing a new means of delivering immersive 3D content.

"As space-as-a-service becomes the mantra for the real estate industry, real estate developers, property owners, space planners and agents need a streamlined way to digitise their offerings," said Hexagon's Geosystems Executive Vice-President Ken Mooyman. "With Hexagon's expertise in 3D reality capture, combined with Matterport's computer vision capabilities, real estate and AEC professionals can now access the high-quality content needed to create digital realities of real-world spaces from anywhere in the world."

"By partnering with forward-thinking companies like Leica Geosystems, we are furthering our mission to democratise immersive 3D technology, making it easy for anyone to capture and distribute high-quality virtual experiences," stated Matterport CEO Bill Brown. "A broader set of customers will now be able to easily harness Matterport's powerful media platform, giving them more options for reality capture solutions and significantly aiding in the decision-making process throughout a property's lifecycle. We're excited to help these professionals enhance their offerings with our technology."

Attendees of HxGN Live 2018 were able to witness the the integration between Leica Geosystems' and Matterport's technologies first-hand via numerous demonstrations.

For more information about the Leica BLK360, please visit leica-geosystems.com/en-us/products/laser-scanners/scanners/blk360. For more information about Matterport, please visit matterport.com.

Leica Geosystems Combines New UAV Technology with DJI Aerial Platform

Heerbrugg, Switzerland, 12 June 2018—Leica Geosystems, part of Hexagon, industry leader in measurement technology, announced today the new Leica Aibot, the latest Unmanned Aerial Vehicle (UAV) system based on DJI's aerial platform, the M600 Pro, to rapidly and autonomously acquire mobile 3D mapping data.

The new Leica Geosystems UAV technology allows users to get a complete data set in less time with a user-friendly and innovative interface, opening new business opportunities while spending less time, costs and effort than with traditional methods. Leica Geosystems software suite supports the new UAV workflows. Using Leica Infinity for point cloud, digital surface model and orthophoto generation enables surveyors to easily process and visualise aerial data to maximise productivity and speed-up data delivery. Supporting users to share data to Cylcone and Cloudworx, the integration of the UAV point cloud with terrestrial scan data enables users to make the most informed decisions. This complete set of data results in higher project efficiency.

"With constant new ideas, projects and numerous challenges it is crucial for our business to have access to transformational technologies such as the new Leica Aibot, that keep our projects on schedule with the maximum accuracy and precision," said Martin Schwall, owner and managing director of IngenieurTeam GEO. "We look forward to continue using Leica Geosystems technology and adding Leica Aibot to our portfolio."

Automating operations

The new UAV technology, developed in partnership with DJI, the world's leading manufacturer of UAVs, allows users to process and analyse millions of data points gathered from above and visualise the data to provide actionable information. UAV data can be combined with existing survey technologies, such as TPS, GPS and laser scanning, providing a more complete set of information.

"We are very excited to offer our robust and reliable DJI M600 Pro along with our developer tools to Leica Geosystems to empower survey professionals to get a truly efficient solution workflow with the best results and accuracy," said Jan Gasparic, Head of DJI Enterprise.

Throughout a project lifecycle of planning, designing and construction, Aibot provides easier access to critical information to perform volume calculations and monitor site progress. From creating digital terrain models to stripping and bulk earthworks and trenching to finally fine grading, paving and compaction, the solution supports easier actuals comparisons. This provides a more transparent view of site progression monitoring and volume calculations with safer operations to keep projects on schedule.

The Aibot can identify gaps early with a level of accuracy previously unknown for the construction industry. High definition imagery and 3D mapping allow for the viewing of site mapping or progress documentation, meaning users save time and money at all stages of the project.

"The Leica Aibot opens tremendous amounts of opportunity and helps the customers to speed up digitisation of processes and to automate existing workflows," says Valentin Fuchs, Leica Geosystems UAV product manager. "It enables customers to run businesses that are more efficient than their predecessors and be more profitable."

Further information about the Leica Aibot can be found at leica-geosystems.com/products/uav-systems.

SimActive Software for Precision Agriculture in Brazil

Montreal, Canada, June 12th, 2018—SimActive Inc., a world-leading developer of photogrammetry software, is proud to announce use of its software for precision agriculture in Brazil by Portal Produtos Agropecuários Ltda (Portal). Drone data is transformed into useful and pertinent information for farmers with Correlator3D, leading to optimized yields and reduced costs for the agricultural season.

The identification of the presence and damage caused by centipedes was one such example. When plant samples from the field were collected to identify the source of the growing anomaly, Portal was able to fly and generate mosaics to spot the problem within 24 hours using Correlator3D and their drones.

"Correlator3D is agile, reliable, and efficient in processing the high-resolution UAV data we collect, generating high quality mosaics every time", said Valdir Rago, Agronomic Engineer at Portal. "We tested other commercial UAV data processing apps and found that Correlator3D was the best at delivering the results we need. The friendly interface, also accessible in Portuguese, along with round the clock support from SimActive's partner in Brazil, ENGESAT, put them in a different league."

For More Info visit www.simactive.com

The INTERGEO conference is training the spotlight on digitalization from various perspectives

Karlsruhe/Frankfurt am Main, 20 June 2018—INTERGEO 2018 presents the ideal opportunity to explore key topics surrounding the digital revolution, smart cities and ever-advancing technological developments such as artificial intelligence and augmented and virtual reality. Tickets for the conference and trade fair are available now. Keynote speeches, panel discussions and industry-focused exhibitions will demonstrate the bright prospects for the future geodata industry.

When it comes to digitalisation, the question on everyone's lips is "where?". This is precisely where geodata comes in. Geodata forms a key part of each digitalisation process and is often needed to make such processes worthwhile and understandable. Google is a prime example with Google Maps. "Geodata naturally plays a vital role in digitalisation, as we live in a 3D world where something is always happening somewhere," says Prof. Hansjörg Kutterer, President of the INTERGEO host, DVW (German Society for Geodesy, Geoinformation and Land Management). "A digitalised world calls for geodata. It is essential for smart cities, as various forms of specialist data can be combined with digital geoinformation to provide new findings. The data can then be used for a whole range of purposes, from generating forecasts to providing services. Just think of the tasks in urban and traffic planning, environmental protection or disaster prevention, for instance. The world of work will fundamentally change, as will citizens' expectations. Only by incorporating geodata can we turn elementary applications in the cities of the future into smart solutions."

That's why the smart city solutions section constitutes the focal point of the trade fair. An important partner in this respect is the Fraunhofer Institute for Industrial Engineering (IAO), which is working hard to address the subject and will give a keynote speech on the Wednesday with Alanus von Radecki to provide visitors with an expert insight.

Smart traffic management by means of autonomous driving, digital urban planning, digital construction and property valuations are just some of the main focuses at the conference. Prof. Joaquin Diaz from the Federal Association of Construction Software (BVBS) and Prof. Harald Simons, member of the management board at empirica AG, will kick off the final day of the event with a keynote speech on these subjects.

Looking at infrastructure measures, Ron Bisio from Trimble will give a keynote speech on building information management (BIM) and highlight the potential of state-of-the-art geospatial technology.

Even now, vast amounts of precise and cutting-edge geodata are being collected. AI has the potential to make data capture and evaluation processes significantly faster, which will see construction procedures and traffic management undergo revolutionary changes in the future. AI planning expert Prof. Jürgen Döllner from the Hasso-Plattner Institute will open the event with a keynote speech focusing on the different uses of AI.

The visualisation of geodata is increasingly based on high-resolution, photorealistic virtual reality (VR) applications that exhibit state-of-the-art imaging and scanning processes. On top of that, there are augmented reality (AR) applications that enable users to directly access location-specific data that can be geographically and seamlessly combined with a digital 3D depiction of the area.

INTERGEO is the world's largest trade fair for geodesy, geoinformation and land management and therefore provides a fantastic platform, forum and opportunity to network. The 2018 event will be held in Frankfurt am Main, Germany, from 16 to 18 October.

Dewberry Selected to Update High-Resolution Lidar for Puerto Rico and U.S. Virgin Islands

Firm will produce more than 3,600 miles of post-Hurricane Maria topographic lidar data

Fairfax, VA—June 6, 2018—The U.S. Geological Survey (USGS) has selected Dewberry, a privately held professional services firm, to collect and process Quality Level 1 topographic lidar data of Puerto Rico, including the islands of Culebra, Vieques, and Isla de Mona; and the U.S. Virgin Islands of St. Croix, St. John, and St. Thomas. The new data will be used to identify the impact of Category 5 Hurricane Maria, which struck the territories in September 2017. The project will be completed under Dewberry's Geospatial Product and Services Contract with USGS to support the 3D Elevation Program.

Dewberry has been performing mapping, mitigation planning, and sea level rise studies in Puerto Rico for more than ten years, primarily serving the Federal Emergency Management Agency (FEMA). In a similar effort, the firm recently collected and processed more than 3,400 square miles of topographic and bathymetric lidar data for USGS, the National Oceanic and Atmospheric Administration (NOAA), and the Commonwealth of Puerto Rico. For that project, the data were collected prior to Hurricane Maria's landfall, and the new data will be assessed in comparison to that dataset to evaluate the storm's impact. Lidar data have not been collected for the U.S. Virgin Islands in more than ten years.

The new lidar data will be collected, processed, and delivered by the spring of 2019. Dewberry will perform all ground surveys and its geospatial team will complete the processing and creation of digital elevation models and other ancillary products. The firm's subconsultant, Leading Edge Geomatics, will perform the data acquisition using two Riegl VQ1560i sensors.

"The pre-storm data we had collected and processed under our prior task order was instrumental in assisting FEMA, its partners, and the local Puerto Rican government in planning and conducting its post-Maria disaster recovery work," says Amar Nayegandhi, CP, CMS, GISP, vice president of geospatial and technology services for Dewberry. "The new data are being collected at a higher density to also support the infrastructure community and will show how the storm has altered the terrain."

For More Info, visit www.dewberry.com

Martin Flood Joins Teledyne Optech as Director of Business Development

June 12, 2018 — Teledyne Optech is pleased to announce that Mr. Martin Flood has joined the company as Director of Business Development. In this global role, Mr. Flood will concentrate on expanding the reach of the Teledyne Optech product portfolio to new markets, and will identify and oversee the execution of new business opportunities.

Mr. Flood started his career at Optech as a Project Scientist in 1991 and led the team that produced the first Airborne Lidar Terrain Mapping (ALTM) sensors. After leaving in 1997 and working for several mapping service companies, he joined the GeoCue Group as Business Development Manager in 2005. A major focus of his work was identifying new and emerging markets for lidar-related mapping services and helping customers adopt established best practices for new business models.

"I am extremely pleased to welcome Martin back to Teledyne Optech," said Michel Stanier, EVP and General Manager of Teledyne Optech. "In the mid-90's, Martin led the creation of the ALTM team which spawned the vibrant industry that we know today. Since then Martin has been actively involved in the industry, first as a service provider, then as a solutions provider. This market experience, combined with Martin's solid understanding of the underlying technology and the opportunities to apply it in innovative ways, will greatly strengthen our ability to continue to lead and blaze new trails."

"I am excited to be taking on the role of Director of Business Development for Teledyne Optech because of the enormous potential I see for lidar and imaging technology across numerous industries," said Mr. Flood.

"I feel the most significant opportunity going forward is to embed Teledyne Optech's lidar and imaging technology at the core of the geospatial revolution that is occurring across many industrial, scientific, medical, and photogrammetric applications."

Find out more at www.teledyneoptech.com.

IN-FLIGHT Data and senseFly Team Up for Beyond Visual-Line-Of-Sight Drone Trial

Calgary, Canada / Cheseaux, Switzerland, June 4, 2018—One of Canada's leading commercial drone operators, IN-FLIGHT Data, this week is embarking upon Canada's largest BVLOS UAS Operations trial to date, with support from senseFly, the industry's leading provider of professional mapping drones and a commercial drone subsidiary of Parrot Group.

The project's goal is to demonstrate that BVLOS UAS flights can be conducted safely and efficiently, to the benefit of all Canadians, while providing cost reductions and/or operational efficiencies for the different use-cases involved.

"We are truly excited to get the go ahead for this ambitious project," said Chris Healy, the owner of IN-FLIGHT Data. "Working closely with senseFly and our 20 partner organisations, we'll be collecting a huge amount of geo-accurate data—across many types of long-range drone applications—which we are confident will help contribute to the creation of pragmatic future BVLOS legislation."

"The scope of this trial is, we believe, unique in Canada, if not the region," added senseFly's Regulatory Project Manager, Samuel Dépraz. "The vast amount of flight safety data and learnings that Chris' team will collect and share will be extremely beneficial to the future growth of Canada's commercial drone industry, and I'm sure other regulators around the world will be following this project with interest. With IN-FLIGHT Data's extensive operational experience, the project's diverse, committed partners, and its 'Compliant' senseFly drones, I've no doubt this trial will be a success."

IN-FLIGHT Data's trial will run until early November. During this time the company will aim to complete one BVLOS mission per week. Defined by the trial's 20 partner organisations, these missions will span everything from pipeline surveys and crop mapping to landfill volume analyses, graveyard inventory assessments and even search and rescue applications.

Key trial statistics include:

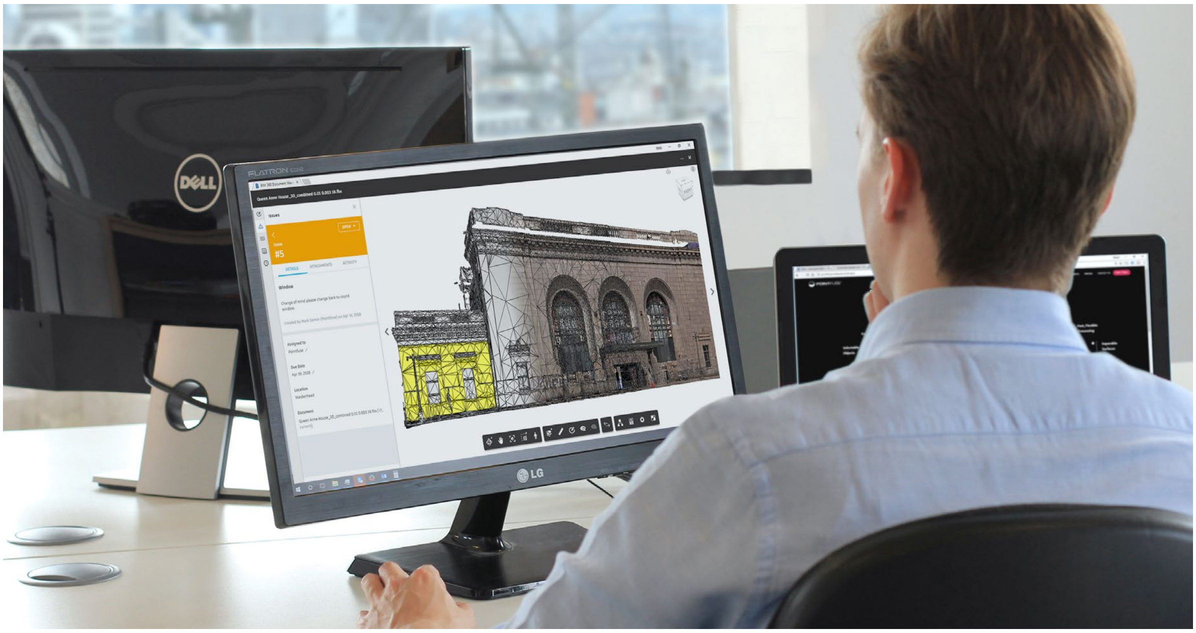
- 14 different test sites: some specific Transport Canada 'in-range' sites, others 'off-range' open airspace sites in rural locations.
- 2 drones (UAS): senseFly eBee Plus & senseFly eBee
- Flights up to 10 km in length
- Over 1,500 km total linear flight distance
- More than 120 datasets: spanning both RGB and thermal infrared aerial imagery.
- Human observers will monitor flights and air traffic in order to compare their observations, for example, with operators' ground station software experiences.

"The reasons we made this trial so large are two-fold," said Healy. "The more data, the better the risk models Transport Canada can create, which will help them to create safety-focused BVLOS regulations that benefit everyone. And secondly, there are just so many potential BVLOS applications out there, we really wanted to explore a good number of these."

The flight safety data collected during the trial will be provided to Unmanned Systems Canada and TC to help define BVLOS risk models for different categories of unmanned aircraft. In the case of IN-FLIGHT Data, the eBee and eBee Plus drones it will use during the trial, designated 'Compliant' systems by TC, fall within Canada's TC's proposed 'Very Small' (sub-1kg) and 'Complex operations (urban)' commercial drone categories respectively. These UAS will be operated using senseFly's commercial-grade eMotion ground station software, which includes integrated air traffic and geo-awareness data—key to running safe BVLOS operations in non-controlled airspaces—courtesy of AirMap and uAvionix air traffic data systems.

In 2017, senseFly became the first drone operator to be granted 'anytime' Beyond Visual Line of Sight (BVLOS) authorisation in Switzerland, plus its systems are currently approved for BVLOS use in France, Spain, Denmark and China. senseFly was also one of several organisations that were instrumental in the success of last year's ground-breaking Unmanned Traffic Management (UTM) demonstration in Geneva (Swiss U-space demo). The eBee Plus, eBee SQ and albris were designated 'Compliant Unmanned Aerial Vehicles (UAV)' by TC in August 2017, while senseFly's original eBee drone became Canada's first compliant fixed-wing drone back in 2015.

For More Info, visit www.sensefly.com/drones



Pointfuse Unlocks 'As Built' Data for BIM with Autodesk Integration

Maidenhead, UK, 31 May 2018—Pointfuse, a software provider that converts laser scan data - known as point clouds - into 3D models, has announced its integration with Autodesk's BIM 360 project delivery platform, the first single project platform connecng design through construction. Pointfuse has pioneered new techniques to rapidly process vast point cloud datasets into intelligent and easy to handle mesh models. This innovation will allow important 'as built' models to be easily incorporated into Building Information Modelling (BIM) workflows managed with Autodesk BIM 360.

"Digital Construction is about supplementing existing work flow practices in an online collaborative environment," said Jon Boyce, CEO of Pointfuse. "Collaborative design is well established as a deliverable in digital construction. As a leading provider of robust design and construction software, Autodesk is the natural partner for us to introduce this exciting development in reality capture to achieve 4D BIM."

"The integration of Pointfuse with BIM 360 bridges the gap between the physical and digital worlds, and allows a far more connected and efficient construction process," says Sarah Hodges, Sr. Director, Construction Business Strategy and Marketing at Autodesk. "When reality capture data is exported to BIM 360, Pointfuse models allow easy comparison to the original design at each stage of the building process and puts all the project data into a single platform, breaking down silos that currently exist among various technologies."

4D BIM is a way of live-tracking project progress so stakeholders can view the current status and collaborate online using the BIM 360 platform. The latest scheduling and updated costings, changes and identification of potential clashes all require timely and accurate "as built" data as an integral part of the process.

"Crucially Pointfuse as built models will help with the avoidance of design clashes. This is important since, industry-wide, it is estimated that each identified clash could save up to $15,000 on a large scale project," comments Boyce.

Democratization of data from job sites has been a process of box ticking and photography which is traditionally a manual and cumbersome process. The data compiled is considered to be of low value and rarely adopted in a complete work flow process. New rapid scanning technology offers the potential to change this, but the resulting point cloud is difficult to interpret by the untrained eye. Its use in a browser based collaborative environment is also compromised by the large data file sizes. Pointfuse addresses this with software that creates relatively small but accurate and intelligent models that are manageable within a cloud environment.

Pointfuse is available as a download from the Autodesk App store as a full integration with BIM 360.

For More Info, visit www.pointfuse.com

The Smart City at INTERGEO—Discover the Urban Future

Karlsruhe/Frankfurt, 30 May 2018—Cities of all sizes are currently working on offering their growing populations attractive, sustainable living spaces, so smart city solutions are booming. These cities are faced with huge traffic, energy, environmental, health and education challenges and each of them requires its own specific solutions. INTERGEO considers this development and the rapidly growing market for smart city solutions to be extremely important, as reflected by both the conference programme and the SMART CITY SOLUTIONS topic platform that acts as a meeting point for providers of such solutions.

The urban era has only just started. According to the latest figures from the United Nations, around three-quarters of the world's population will be living in cities by the year 2050. This trend is even further advanced in Germany. According to a study published on the "Statista" statistics portal, some 78.6 percent of the country's population will be living in cities by 2030. An entire generation of urban planners and developers, traffic and environmental experts, local politicians and municipal energy providers are therefore joining research institutions and EU projects in addressing the question of how to prepare cities for this additional population pressure.

> "According to figures from the United Nations, around three-quarters of the world's population will be living in cities by the year 2050."

What will the smart city of the future look like?

To ensure cities become attractive and adaptable living spaces in the future, cutting-edge IT is being used on a widespread basis to turn them into smart cities. But what exactly does that mean? What aspects of urban life are affected? And how are city dwellers reacting to this digitalisation of their living environment? There is no definitive answer to any of these questions because every city is unique and has its own requirements and challenges. The starting point for every smart city is therefore to analyse local features and the goals of local authorities and the people living there. A wide range of data needs to be collected and analysed along with existing information, and the basic function of geodata is deemed extremely important in this regard.

Basis for healthy urban growth

INTERGEO sees the smart city as a basis for healthy urban growth and is presenting itself as a platform for this dynamic sector of the economy. The topic is a focal point during all three days of the INTERGEO Conference. The "Local authorities and digitalisation", "Smart city" and "Lighthouse city Germany" programme blocks follow the steps involved in cities becoming smart and underline the importance of geoinformation throughout this process.

Networking providers and cities at SCS

SMART CITY SOLUTIONS is a meeting point for international providers of smart city tools and the people responsible for urban development, mobility and the environment in cities and communities. Thomas Müller and Bart Gorynski from the "bee smart city" internet platform, an exhibitor and panel organiser at SMART CITY SOLUTIONS, define a smart city as an ecosystem of solutions and have the following to say: "We're delighted to actively support SCS precisely because its fundamental objective is to highlight the many different facets of the smart city and bring together providers and the cities themselves." Mitsubishi Electric is also exhibiting at INTERGEO. The Japanese company sees its mobile mapping system and automated mapping technologies as the basis for driverless vehicles, efficient infrastructure management and disaster protection. It regards INTERGEO as an ideal opportunity to meet partners for the future who are keen to pave the way for new, innovative business models and markets.

All this is exactly what SMART CITY SOLUTIONS is aiming for, providing a platform for providers to network and meet city representatives, and also for cities to enter into dialogue and compare their solutions.

Smart city solution providers, urban developers and planners, environmental and traffic experts, economic development specialists, urban consultants and local authorities can discover the urban future—in Frankfurt from 16 to 18 October at INTERGEO, the accompanying conference and the special part of the trade fair devoted to SMART CITY SOLUTIONS.

Receive a free ticket to the fair with voucher code **"AmSurv"**

For More Info, visit www.intergeo.de/intergeo-en/

RON ROTH HELPS STEER SINGLE-PHOTON

A Tale of People, Acquisitions and Technology

In the early years of this century, Leica Geosystems' lidar guru Ron Roth and *LIDAR Magazine* managing editor Stewart Walker were both employed by LH Systems and then Leica Geosystems. Stewart decided to renew the acquaintance and find out what's going on in lidar at Hexagon's Geosystems Division's subsidiaries Leica Geosystems and Sigma Space. He visited Leica Geosystems and its Sigma Space operations in Lanham, Maryland on 1 March 2018 and here's what he discovered. This is the first article: the focus is on linear-mode lidar for both topographic and bathymetric applications, followed by an introduction to single photon. The Sigma Space subsidiary and its single-photon innovations will be described in depth in the second.

Ron moved to the Lanham facility in 2016. We settled into his office and I noticed the names on the doors of neighboring officers—John Welter (see below), Bruce Wald (see below) and Belai Beshah, another former colleague from LH Systems in San Diego, but now vice president—software development, Hexagon Geospatial Content Solutions (GCS). As ever, Ron was urbane and elegant, but has not abandoned his disconcerting yet endearing habit of diverging into well rendered sketches from *Monty Python's Flying Circus*, as well as irrelevant references to classical architecture.

BY DR. A. STEWART **WALKER**

Ron's job title is Product Manager—Airborne Topographic Lidar for Hexagon's Geosystems Division's GCS. As acquisitions are integrated into a large company, managers' roles are molded and clarified. Ron reports to John Welter, division president, GCS, who arrived by way of the acquisition of Northwest Geomatics, Calgary, Canada, in 2014. Also reporting to John is vice president Anders Ekelund, who came to Hexagon as a result of its acquisition in 2013 of Airborne Hydrography AB (AHAB), Jönkoping, Sweden. The structure enables Anders to focus on business and product development for the bathymetric lidar market. Poul Norgård, chief product officer, joined Geosystems from COWI, a mapping services customer in Denmark. Klaus Neumann, who arrived through Z/I Imaging, Aalen, Germany, part of the acquisition of Intergraph by Hexagon in 2010, is now vice president technical sales and also provides product guidance for imaging. His role in providing technical support to the sales operation will grow and will embrace lidar.

Thus, the team is truly international on both the product management and development sides. Ron himself came from Azimuth Corporation, Westford, Massachusetts, which was acquired in 2001 by LH Systems, a joint venture formed in 1997 by Leica Geosystems and the U.S. corporation GDE Systems (now part of BAE Systems).

20 YEARS of Airborne Lidar

ALS PRODUCT LINE RETROSPECTIVE

ALS40 COMPONENTS
(1998 – 2003, S/N 001 - 015)

Large aperture scanner for high-altitude work

Scanner assembly
- 23.5 x 35.8 x 21.8 inches, 120 lb
- 60 x 91 x 55 cm, 55 kg

Equipment rack
- 19.0 x 20.6 x 25.0 inches, 140 lb
- 48 x 52 x 64 cm, 64 kg

Laptop control computer

Post-processing software

45 kHz max pulse rate

70 Hz max scan rate

ALS50-I + COMPONENTS
(2003-2006, S/N 016 - 049)

Compact system for installation on many aircraft types

Scanner assembly
- 21.2 x 14.4 x 9.8 inches, 80 lb
- 54 x 37 x 25 cm, 36 kg

Equipment rack
- 19.0 x 20.6 x 25.0 inches, 140 lb
- 48 x 52 x 64 cm, 64 kg

Laptop control computer with GUI

Post-processing software

83 kHz max pulse rate

77 Hz max scan rate

ALS50-II COMPONENTS
(2006-2008, S/N 051 – 105)

Further refinements with expanded altitude range

Variants: ALS50-II, Corridor Mapper and MPiA

Scanner assembly (L/W/H)
- 21.2 x 14.4 x 9.8 inches, 80 lb (sm)
- 25.6 x 16.3 x 9.8 inches, 91 lb (lg)
- 54 x 37 x 25 cm, 36 kg (sm)
- 65 x 41 x 25 cm, 41 kg (lg)

Rackless electronics (W/D/H)
- 17.6 x 24.5 x 14.0 inches, 88 lb
- 45 x 63 x 36 cm, 40 kg

Operator OC50 with FCMS flight navigation and separate ALS GUI

Pilot OC50 with FCMS flight navigation

Pilot GI40

Post-processing software

150 kHz max pulse rate

90 Hz max scan rate

Azimuth Corporation

Ron's career began after a BSc degree in mechanical engineering from Worcester Polytechnic Institute in Worcester, Massachusetts, to which he later added an MBA from Babson College, Babson Park, Massachusetts. By the early 1990s, he was working with Doug Flint in Holometrix, Cambridge, Massachusetts. Holometrix won a number of Department of Defense (DoD) Small Business Innovation Research awards in the optical range-finding domain. Indeed, the potential of laser measurement for mapping was well understood and mentioned in the paperwork associated with some of these awards, dating back to the late 1980s. In 1991 Doug, Ron and colleague Bob Eaton took private two parts of Dynatech Scientific—Holometrix's electro-optics group and an acquisition, Associated Controls and Communications, which was involved in electro-optics and radar technology. Bob had worked for Dynatech Scientific and its predecessor. Doug, Bob and Ron, therefore, shared an electro-optics R&D background that stood them in good stead as the years passed.

Thus the three engineers founded Azimuth Corporation and moved into modest premises in Westford. Ron emphasized that they founded Azimuth to focus on precise optical ranging, not lidar, which became important to them only in 1998. They worked on laser rangers and profilers and initially performed on DoD contracts before

ALS60 COMPONENTS

(2008-2011, S/N 6105-6159+)

More robust design and even higher productivity

Availability: ALS60, Corridor Mapper, WDM65 Waveform Digitizer Module and MPiA

Scanner assembly (L/W/H)

- 23.7 x 14.5 x 10.7 inches, 93 lb
- 60 x 37 x 27 cm, 42 kg

Rackless electronics (W/D/H)

- 17.6 x 24.5 x 14.0 inches, 99 lb
- 45 x 62 x 36 cm, 45 kg

Operator OC52/OC50 with FCMS flight navigation and FCMS ALS Sensor Control ('09)

Pilot OC50 with FCMS flight navigation

Pilot GI40

Post-processing software

200 kHz max pulse rate

100 Hz max scan rate

ALS70 COMPONENTS

(2011-2014, S/N 7160-7234)

Dual-output Lidar for increased pulse/scan rates

Availability: dual-output scanners ALS70-CM (City Mapper) and ALS70-HP (High Performance); single-output scanner ALS70-HA (High Altitude)

Scanner assembly (L/W/H)

- 23.7 x 14.5 x 10.7 inches, 93 lb
- 60 x 37 x 27 cm, 42 kg

Rackless electronics (W/D/H)

- 17.6 x 24.5 x 14.0 inches, 99 lb
- 45 x 62 x 36 cm, 45 kg

Operator OC52/OC50 with FCMS flight navigation and FCMS ALS Sensor Control ('09)

Pilot OC50 with FCMS flight navigation

Pilot GI40

Post-processing software

500 kHz max pulse rate (ALS70-CM/ALS70-HP), 200 kHz max pulse rate (ALS70-HA)

200 Hz max scan rate (ALS70-CM/ALS70-HP), 100 Hz max scan rate (ALS70-HA)

User-selectable scan patterns (sine, triangle, raster)

ALS80 COMPONENTS

(2014-, S/N 8235-8247+)

Improved scan geometry, laser and GNSS/IMU

Availability: dual-output scanners ALS80-CM (City Mapper) and ALS80-HP (High Performance); single-output scanner ALS80-HA (High Altitude)

Scanner assembly (L/W/H)

- 23.7 x 14.5 x 10.1 inches, 103 lb
- 60 x 37 x 26 cm, 47 kg

Rackless electronics (W/D/H)

- 17.6 x 24.5 x 9.5 inches, 72 lb
- 45 x 62 x 24 cm, 32 kg

Operator OC60 with FlightPro flight navigation and ALS Sensor Control

Pilot PD60 with FlightPro flight navigation

CloudPro post-processing software

1.0 MHz max pulse rate (ALS80-CM/ALS80-HP), 500 kHz max pulse rate (ALS80-HA)

200 Hz max scan rate (ALS80-CM/ALS80-HP), 100 Hz max scan rate (ALS80-HA)

User-selectable scan patterns (sine, triangle, raster)

HEXAGON
LINEAR-MODE TODAY

CITYMAPPER

In the very first meeting between Azimuth Corporation and LH Systems, almost 20 years ago, the concept of very close integration of lidar and image acquisition systems was discussed! Now it has been implemented in a hybrid sensor, Leica CityMapper: the optics for four oblique RCD30 CH81 three-band and one vertical RCD30 CH82 four-band 80-megapixel camera heads can be seen surrounding the bigger optic of the Hyperion lidar (700 kHz maximum pulse rate, 100 Hz maximum scan rate). The circular shape of the housing fits in the Leica PAV100 gyro-stabilized mount. CityMapper is designed for urban mapping. The post-processing workflow includes the Leica HxMap and Leica RealCity software products, which can result in a city model like the one in the background.

TERRAINMAPPER

Complementing Leica CityMapper is Leica TerrainMapper, designed for large-area acquisitions and combined with Leica HxMap and Leica RealTerrain software. This hybrid sensor features high-performance lidar ((2.0 MHz maximum pulse rate, 150 Hz maximum scan rate) and the option of a vertical RCD30 CH82 four-band 80-megapixel camera head. For easy recall, Ron distinguished between the two hybrid systems in a sentence, “CityMapper is cameras with lidar, TerrainMapper is lidar with a camera.”

developing a commercial airborne lidar product. He remembered affectionately the skills of the Westford group, which developed the first commercial airborne lidar product in only nine months. Indeed, there is an ASPRS film that documents the foundations of lidar: watch asprs.org/news/asprs-films/asprs-films-viewer.html.

Every few months Ron received a call, typically from someone in the mapping business, asking if Azimuth could add a scanning mechanism together with GPS and IMU to one of its high-speed, precise optical range-finding systems, but nothing happened because initial costs were too high. Finally, in 1997, another call came from Photo Science (subsequently EarthData, now part of Fugro), asking Azimuth to develop a high-altitude lidar system to fly with imaging systems acquiring USGS DOQQ images at 6000 m flying height and 75° FOV. Azimuth had already put systems in aircraft, with GPS but no IMU, just an assumption that the system was pointing approximately nadir. The 20-pulses-per-second technology (yes, 20 Hz!) could produce only one point every tens or even hundreds of meters. This was similar to the approach known to photogrammetrists in the early days as airborne profile recorder. Georeferencing was rudimentary, little more than just timing, to estimate where the aircraft was when the laser was fired. At best, they had a vertical gimbal to provide a broad approximation to nadir pointing. Nevertheless, an agreement was reached with Photo Science, and work began.

By August 1998, the components of the system had been gathered and integrated. The team drove to Photo Science’s flight center in Hagerstown, Maryland and installed the prototype in an aircraft. It worked and the first unit was sold in late 1998, followed

MODERN BATHYMETRIC SENSORS

CHIROPTERA II

The Leica Chiroptera II is Hexagon's shallow-water topo-bathymetric lidar for coastal surveying to ~1.5 Secchi depth down to 25 m. It combines a 35 kHz bathymetric channel with a green laser and a 500 kHz topographic channel with an infrared laser. There is a small camera for QA purposes and the option of a vertical RCD30 CH82 four-band 80-megapixel camera head. The software workflow includes Leica Survey Studio.

HAWKEYE III

Hexagon's deep-water bathymetric lidar solution is Leica HawkEye III, with capabilities of ~3.0 Secchi depth down to 50 m. It combines a 10 kHz bathymetric channel for deep water, a 35 kHz bathymetric channel for shallow water down to 2 m depth and a 500 kHz topographic channel. These have green and infrared lasers respectively. The camera and software provisions are similar to Chiroptera II. Indeed, an upgrade from Chiropetra II to HawkEye III is available. The background schematic illustrates a complete system mounted in an aircraft.

by two more in 1999. The marketing effort lagged the technology, however—Azimuth had no website and only one e-mail address—but four more units were sold in 2000. Azimuth worked closely with EarthData and other mapping companies, such as Vernon F. Meyer, New Orleans, Louisiana (which became part of 3001, later acquired by Northrop Grumman in 2008), often developing new features with each sale.

Meyer had no aircraft and relied on partners with aircraft and sensors to collect data for them. One of these was Northwest Geomatics, so the relationship began with John Welter, who was heavily involved in the technical management of the company's flying operations and the performance of its sensors. John gave a contact name to Ron—Stewart Walker at LH Systems in San Diego, California, of which Northwest Geomatics was a customer. During the ISPRS Congress in Amsterdam in 2000, at which LH Systems launched the revolutionary ADS40 airborne digital sensor, Stewart called and invited Ron to make a presentation at their next user group meeting. Azimuth was seeking other outlets for its technology—or investors, capital or an exit strategy. A graphic of Azimuth's AeroScan was doctored to look as if it was in Leica Geosystems green livery with orange trim and renamed "ALS40?". Azimuth was interested in using LH Systems for marketing, for a finder's fee, or private labeling, or investment. But Bruce Wald, CEO of LH Systems, perceived a danger: if both companies had to generate their required gross margins on the same product, the resulting price point would be higher than competitors'. The solution was acquisition, completed in April 2001. This was a time of great change: a month later, LH Systems was re-purchased by Leica Geosystems (itself created in 1997 as Leica split into smaller units), which had acquired Cyra Corporation, San Ramon, California in 2000 and ERDAS, Atlanta, Georgia in 2001.

Leica Geosystems set up a GIS & Mapping Division, managed by Bob Morris (now at GeoLearn). Bruce Wald left Leica Geosystems for 15 years, but has returned as chief operating officer, content programs, GCS. Leica Geosystems and Intergraph were acquired by Hexagon in 2005 and 2010 respectively. These tumultuous times resulted in a remarkable product range, of which the ALS-series lidar systems were an important part. Doug Flint eventually left Leica Geosystems. Bob Eaton continued in the company until shortly before his passing in 2015.

ALS-series

Ron characterized the market-place. Teledyne Optech (at that time it was just Optech, since the Teledyne acquisition did not occur until 2015) was already up and running. RIEGL of Austria was another dangerous competitor, as was Schwarz Electro-Optics in Orlando, Florida. Those were the competitors in optical range-finding, but Optech had the lead in the early and mid 1990s, in what we now know as airborne lidar, with its ALTM 1020.

Azimuth was not taken particularly seriously until the acquisition by LH Systems. Optech had sold about 25 units before Azimuth sold its first. Sensors had also been fielded by RIEGL, often within other suppliers' systems, since RIEGL tried to make its systems easy to integrate, for example with OEM GNSS/IMU subsystems. Optech's were more turnkey. The Azimuth unit, however, could operate at greater flying heights than its competitors. Whereas LH Systems had re-sold Applanix GPS/IMU systems and some competitors continue to purchase GNSS/IMU subsystems from OEMs, Leica Geosystems eventually created its own IPAS systems, originally developed by Tim Crago and Dr. Huanqi Sun at Terramatics Technologies in Calgary, which was taken over by Northwest Geomatics. Hexagon also purchased another Calgary GPS system supplier, NovAtel, in 2008 and the remaining employees from the Terramatics Technologies group were moved into the NovAtel facility. Hence, Leica Geosystems lidar sensors currently use NovAtel SPAN GNSS/IMU systems.

> "By August 1998, the components of the system had been gathered and integrated. The team drove to Photo Science's flight center in Hagerstown, Maryland and installed the prototype in an aircraft. It worked."

Ron fondly recalled the 2000-05 period, when many companies invested in lidar systems and market absorption was high. The competing vendors were pushing as many as 60 units into the market every year, at over $1m each. He assiduously maintained a spreadsheet of sales by each vendor and this has grown over the years into a complete catalog of airborne instrument sales and a valuable internal tool.

There was a dip after the "market perturbations" of 2008, but the volume remains sufficient to sustain the three mainstream competitors, though the level of 60 units per year has not yet been repeated. Ron estimated that 700-800 units have been installed on manned aircraft and helicopters, though much depends on how to account for system upgrades, etc. He monitors unique serial numbers, of which Leica Geosystems has 260 in play, but with upgrades this is equivalent to 500-600 systems manufactured. Ron felt that the market for traditional airborne lidar systems is now saturated to some extent, especially since newer systems are more productive than older, enabling more and more data to be acquired each year without fresh system purchases. Productivity has doubled approximately every two years, a sort of Moore's law of lidar. Ron uses effective pulse rate rather than points per square meter to gage this and reckons that the course of development consists of jumps interspersed by rests on a plateau. The use of diode-pumped lasers, the introduction of multiple-pulse-in-air (MPiA) technology and multi-optical-channel systems, for example, have been amongst these jumps.

Airborne Hydrography AB

Ron addressed the AHAB acquisition. The company was founded in 2002 by three Saab employees, to whom Saab had sold the rights to a system. The airborne bathymetric lidar market was a tough one for AHAB to penetrate, as it was predominantly a deep-water one: only one or two systems are sold annually worldwide and the customers tend to be institutional ones such as the U.S. Army Corps of Engineers (USACE).

Optech was by far the largest player. The water penetration of the systems is about three times the Secchi depth, up to 50 m. The Optech SHOALS systems was developed for USACE and, moreover, Optech was in bathymetric lidar before topographic and competed with Saab and the LADS system from Australia. Multi-beam sonar remains the preferred technology for hydrographic charting. Then "shallow-water bathymetry" arrived, with systems offering one times the Secchi depth, perhaps a maximum of 25 m. Leica Geosystems, therefore, perceived the shallow-water market as bigger, since system prices were not so much greater than the topographic ones. Also, in water 30-50 m deep sonar is often feasible, since vessels can often sail safely, and economically, and the swaths are wider at greater depths. Operating in shallow water, on the other hand, is expensive, dangerous or both; if lidar can survey the areas from the shore to waters deep enough for satisfactory sonar operation, then it is a powerful solution. Full waveform digitizing and analysis came with bathymetric systems. Optech, therefore, has been offering this for some time and Riegl has done extensive work on the processing side too, including on-the-fly conversion of waveforms to range data. Leica Geosystems realized that it could bring this full-waveform expertise to its topographic products, as Optech had done earlier.

Sigma Space

At this point, we had covered the first two prongs of Leica Geosystems' airborne lidar triad, the ALS-series topographic systems, with their origins in the Azimuth strand of the history, and the bathymetric and topobathymetric systems from the Saab/AHAB side. We turned to Sigma Space. Ron provided me with a succinct introduction to the acquisition, the motivation and the technology, then I was privileged to spend time in the afternoon with Sigma Space CEO and founder, Dr. Marcos Sirota. This fascinating story will be unveiled in the second article. Suffice it to say here that commercial products based on single-photon lidar technology are now part of the Leica Geosystems product portfolio, while application-specific developments in single-photon technology continue to be offered through the Sigma Space operation.

> "Chiroptera and HawkEye III are solutions for shallow and deep water respectively. ALS series will soon go out of production after a 20-year run and be superseded by TerrainMapper."

Ron stated, however, that the airborne lidar product range is simpler than those of competitors. Chiroptera and HawkEye III are solutions for shallow and deep water respectively. ALS series will soon go out of production after a 20-year run and be superseded by TerrainMapper. No sensor suitable for UAVs is currently offered. TLS/MMS is a separate product area.

Content programs

I was curious about Hexagon's enthusiasm for content programs, as it is becoming a data supplier as well as a supplier of systems to enable its customers to acquire data. This wouldn't have happened 20 years ago. Ron felt that the company is attempting to acclimatize the industry to the content-program approach.

There has been some healthy skepticism in the market-place about the Hexagon Imagery Program (HxIP), yet more and more customers want to become partners, because they realize that financial efficiencies are going to drive end-users of data to collaborate on data acquisition. Everyone benefits from a "fly once, use many times" business model. The market seems to have grasped this. The success of content programs, however, is incumbent on the availability of very high-quality, dependable partners. Not everyone has the energy and discipline to generate top quality data.

Ron stated that 3DEP will be a customer—not a competitor. He gave the analog, on the imagery side, of the NAIP program, which consumes imagery that also resides in a content program. In other words, data is acquired and goes to both the government project and the content program. Users purchase data they need from the content program, in a timely fashion, at a lower price, and can do so again in three years. Indeed, Valtus, which was an affiliate of Northwest Geomatics when the latter was acquired by Hexagon already has ALS50-II and ADS lidar data along with imagery. Bruce Wald is COO for the program and I hope to work with him on a future article looking at these programs and the underlying business strategy.

Finally, I asked about multispectral lidar. Ron explained that this simply means multiple lasers in the same lidar system, operating at different wavelengths. The Optech TITAN system, for example, has three wavebands, by using three lasers, which are not co-registered, so the fusion is done in the software. Ron did not commit on whether Leica Geosystems is interested in moving in this direction, though the Chiroptera and HawkEye bathymetric systems are already multi-spectral, with both green and infrared wavelengths used in the same instrument.

More to come!

In the morning, therefore, I had caught up with Ron Roth and seen the ongoing integration of Sigma Space into Hexagon's Geosystems Division. I had enjoyed insight into the complexities of the moving parts of the Hexagon organization—firms, people, places and products—and the intriguing history behind some of them. I had secured an afternoon appointment with Marcos Sirota to "get into the weeds" of Sigma Space. That will be written up in the second article.

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

Vital Deployment of Lidar Data for Emergency Response—Rapid, Effective, Essential

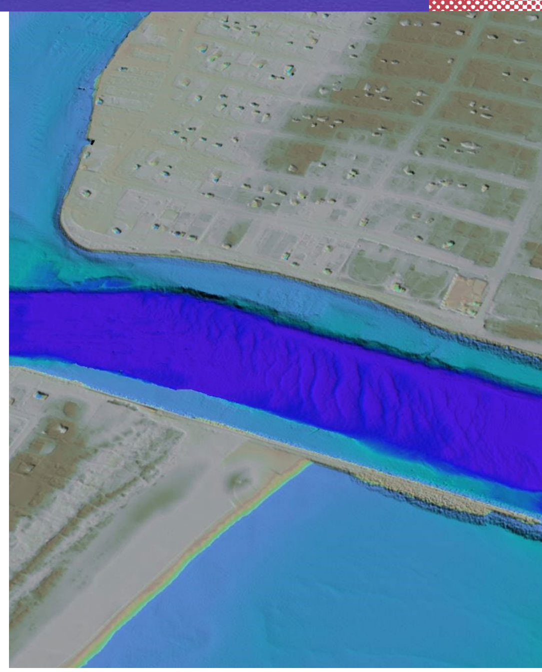
BY JOHN GERHARD

Knowledge is power, and the more we know the stronger we become. In times of distress or disaster, acquiring highly accurate information becomes crucial to recovery and resilience.

Natural disasters cause severe damage to natural and manmade infrastructure across the country. Hurricanes in particular wreak havoc on the shorelines and inlands of coastal states, degrading the integrity of the coasts. Ascertaining the impact made by these disasters better equips disaster response in the short and long term.

When Hurricane Matthew hit the Southeast in October 2016, the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) contracted with WMR-532, a joint venture between geospatial mapping firms Woolpert and Optimal Geo, to acquire bathymetric and topographic lidar and imagery data to provide an immediate, accurate assessment of the affected regions. JALBTCX supports the coastal mapping and nautical charting requirements of the U.S. Army Corps of Engineers (USACE), the U.S. Naval Meteorology and Oceanographic Command, the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS).

USACE deployed JALBTCX for regional-scale, post-storm damage assessments after several major extreme storm events in 2004 (Charley, Frances, Ivan, Jeanne), 2005 (Katrina, Rita, Wilma), 2008 (Ike), 2012 (Sandy), and 2016 (Matthew). JALBTCX deployed



Data for this project was collected at an altitude of 400 meters, or 1,300 feet. The horizontal and vertical accuracy of the topographic lidar data was acquired to meet or exceed the USGS Quality Level 2 standards (QL2).

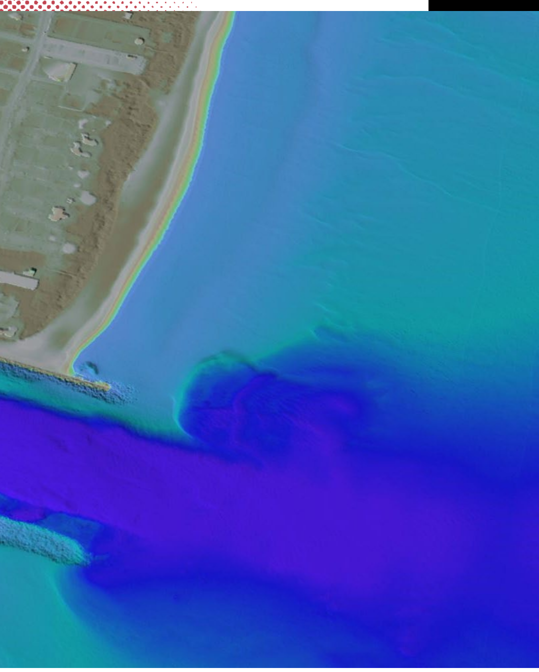
This data is courtesy of the USACE National Coastal Mapping Program.

The data in these images was acquired May 21-22, 2016, with the CZMIL topographic/bathymetric lidar system and processed with HydroFusion software, then cleaned in PFMABE. The data was classified and products developed through GeoCue's LP360 software and used to identify the position/condition of the inlet jetties, as well as the surrounding beach and dunes area in the Lake Worth Inlet area of Florida. The elevation/bathymetric range was 28 meters, relative to NAVD88.

This data is courtesy of the USACE National Coastal Mapping Program.

The data density of these images is 1 point every 0.7 meters in topographic and bathymetric shallow regions, while for deep water the density is approximately 1 point every 2 meters. The data density of the lidar data was acquired to meet USACE Quality Level 2 standards. All lidar data was gridded to generate the 1-meter DEM surface.

This data is courtesy of the USACE National Coastal Mapping Program.



for the Federal Emergency Management Agency (FEMA) in 2005 (Dennis) and 2017 (Irma).

In an abbreviated, four-week time frame, WMR-532 used state-of-the-art, government-owned coastal mapping sensors to provide post-storm data for the shorelines of five states, from Florida through Virginia. The data was processed 24 hours a day in the field and compared to data flown just months earlier, enabling USACE scientists and engineers to analyze and quantify coastal change and beach erosion, and to rapidly identify and address navigation hazards caused by Hurricane Matthew.

"Timely information is a key component to identifying the needs for disaster recovery," said Mark Brooks, chief operating officer of Optimal Geo. "JALBTCX was able to provide USACE Districts, as well as other federal and state agencies, the necessary data to make well-informed, and nearly-immediate, recovery decisions."

Path of Hurricane Matthew

The annual USACE National Coastal Mapping Program (NCMP) operations began in January 2016 in Puerto Rico and resumed in the conterminous states in early May, continuing along the east coast of Florida from late May through July, the Gulf coasts of Florida, Alabama and Mississippi from late July through September, and along the Gulf coast of Texas in September and October by utilizing dual aircraft operations.

Tropical Storm Matthew was declared on 28 September 2016 and grew into a Category 1 hurricane within 24 hours. It reached its peak strength as a Category 5 on 1 October, in the Caribbean Sea just north of the Venezuela/Colombia border. It weakened to a Category 4 as it traversed north through the Windward

Passage between Haiti and Cuba, entering the Bahamas as a Category 3. The hurricane started losing strength as it approached the southeast U.S., side-swiping both Florida and Georgia before making landfall in South Carolina as a Category 1 on 8 October.

Given such a large impact area, USACE South Atlantic Division requested JALBTCX support to capture the condition of USACE projects between Miami and the border between Maryland and Virginia. Extending over 1,000 miles, this stretch of coast contains 35 USACE beach projects designed to reduce the risk of coastal storm impacts and numerous navigation projects that support commercial and recreational shippers, fishers and boaters.

"The importance of these datasets, by that I mean current pre-event data and rapidly delivered post-event data, cannot be understated," said Jennifer M. Wozencraft, USACE NCMP manager and director, JALBTCX. "They allow us to quantify impacts to the coastal environment and infrastructure, and support response activities. But more than that, they help us understand where our vulnerabilities are and how the coastal system responds and give us a baseline for recovery so that we can better adapt, prepare and respond to future storm events."

USACE and WMR-532 equipment and personnel were mobilized from Kiln, Mississippi, starting on 27 October, about 20 days after Hurricane Matthew made landfall in South Carolina and 10 days after the 2016 NCMP operations were concluded in Texas. By the conclusion of the project on 2 December, 991 flight lines had been flown in 76 sorties.

USACE engineers and scientists compared data collected under this contract to data successfully collected along the east coast of Florida in the summer of 2016, just four months before the storm made landfall. For the coasts of Georgia, South Carolina, North Carolina and Virginia, USACE utilized previous NCMP data sets and data sets acquired by federal mapping partners in the Interagency Working Group on Ocean and Coastal Mapping.

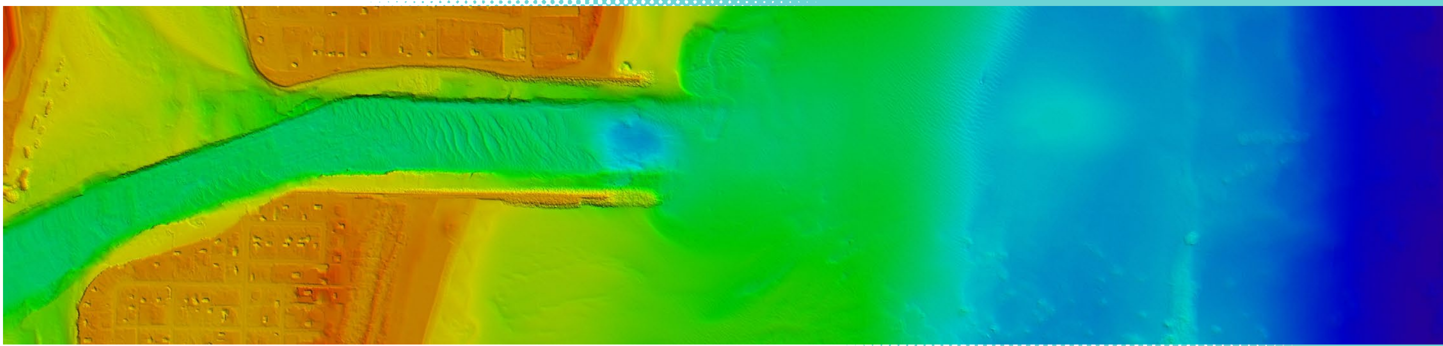
"JALBTCX had current data to utilize and, as Matthew was the first major storm since that last National Coastal Mapping Program acquisition, this project provided exceptionally precise, and temporally relevant, post-storm coastal change analysis," said Mark Smits, Woolpert program director. "Having these resources at hand exponentially increased our application of this data, opening up multiple exciting technological opportunities."

Four field teams were deployed at a Post-Matthew Operations and Production Center in a St. Augustine, Florida, hotel. A staff of between seven and 20 people worked around the clock during those 36 days. Each of the 12 workstations was equipped with a minimum of 32 CPUs, 192 GB of RAM and dual monitors to facilitate the data processing and editing tasks in the hotel's conference room.

Personnel on site included USACE and WMR-532 staff, supporting the data acquisition and data production efforts. Personnel numbers were higher at the start of the post-storm response to support dual aircraft operations, project coordination and oversight. Once flight operations were complete, personnel numbers decreased to levels appropriate to complete the data production in the field.

Data from this rapid-response mapping effort was developed into standardized NCMP lidar and imagery data products, and advanced data products for use in storm damage and impact

The Dynamic Aviation King Air 200 (right) and Kenn Borek Air Basler BT-67 were used in the post-Matthew lidar collection, carrying the CZMIL sensor, owned by USACE and JALBTCX.
Photo courtesy of Optimal Geo.



This topographic and bathymetric 1-meter digital elevation model near-shore lidar data was captured over Palm Beach Inlet, Florida. This data was utilized in conjunction with the 2017 post-Irma survey data to calculate damage.
This data is courtesy of the USACE National Coastal Mapping Program.

assessments by USACE staff. The data delivery schedule called for the delivery of rapid-response data products two days after initial data acquisition, while advanced lidar products were to be delivered two weeks after acquisition.

"Housing JALBTCX's Operations and Production Center in St. Augustine was pivotal in responding to the data needs of scientists and engineers at Jacksonville District," said Charlene Sylvester, USACE senior technical staff member at JALBTCX and post-Matthew QA/QC and production manager. "The site selection afforded opportunities for face-to-face discussions of priority areas, data requirements and product development methodologies to ensure that the data met Jacksonville's science and engineering requirements in a timely fashion and in a data format that was compatible with existing geospatial applications."

Technology Involved in Collection

The sensor used in the post-Matthew collection, Optech's Coastal Zone Mapping and Imaging Lidar (CZMIL), is owned by USACE and JALBTCX, and was installed and flown in a Dynamic Aviation King Air 200 and a Kenn Borek Air Basler BT-67. The combination of aircraft and sensor efficiently and effectively performs on both high-altitude and low-altitude aerial data acquisition.

The CZMIL sensor, operations, and processing are particularly well suited to meet requirements for post-storm mapping. CZMIL is a bathymetric lidar system with capability to collect QL2 topographic lidar, aerial photography, and hyperspectral imagery at the same time. In areas where the water is clear, it can measure sand that has moved off the beach to form sand bars in the nearshore, which is a common beach response to coastal storms. It also is able to measure depths in tidal pools that develop between the beach face and sand bars as they move back onshore, which is a common natural beach recovery mechanism after storms. CZMIL is a low-flying, circular scanning, waveform-resolving lidar, which gives it a unique capability to see through dense vegetation, such as sea grapes, to accurately measure the shape of coastal dunes. The ability to measure these features is key to precisely computing changes in beach elevation and sand volume due to storms.

Mission plans for the post-Matthew project were generated in HydroFusion software, which is unique to JALBTCX's CZMIL sensor suite. Shore-parallel flight lines were organized into 117 flight blocks with 25 percent overlap between adjacent flight lines. A single cross-line per flight block was also planned. An operational altitude of 400 meters above ground level yields a flight line swath width of nearly 300 meters. This altitude is ideal for coastal areas, where cloud deck is low during normal weather, especially during the aftermath of storms.

Post-storm mapping differs from normal airborne survey operations in that data must be collected as quickly as possible after the event to capture the maximum damage of the storm, regardless of weather and water conditions, requiring careful management of the operation of two aircraft in higher than normal water level and wave conditions, and around the priorities of USACE. The goal was to capture USACE projects along Florida's east coast at the outset of this effort, as the USACE projects in the Jacksonville District sustained heavy damage. Wave and water conditions were not optimal for data acquisition during the first several days of operations, which led to the decision to capture projects in the Charleston and Savannah districts first. It took nearly two weeks to complete acquisition for all USACE project priorities.

CZMIL's robust calibration, low flying altitude and intensive QA/QC protocol ensure data with 10 cm $RMSE_Z$ on land and in shallow water without the need for ground control or GNSS base station support. Final data accuracy is validated against prior datasets collected for NCMP and against datasets collected by other sensors. CZMIL operations can be performed without putting a single person at risk in high-hazard post-storm impact areas, or consuming resources such as gas, food, water, rental cars, and hotel rooms that may be needed by people displaced by the storm, or by emergency responders.

JALBTCX employs a standard data production workflow for data acquired under NCMP. The production workflows have been developed in collaboration with USACE staff to ensure that the products meet the needs of engineers and scientists. For this project, the data was processed in the field from raw lidar waveform to edited, unclassified point clouds using the HydroFusion software in conjunction with Pure File Magic Area Based Editor (PFMABE) software. Edited flight line point clouds were then run through an industry-standard ground classification routine and tiled into 1-kilometer-by-1-kilometer tiles per the Military Grid Reference System in Terrasolid's TerraScan environment.

Quality control of those classifications and any further editing was accomplished in GeoCue's LP360, bulk datum transformations were accomplished in NOAA's VDatum, then products were generated using Applied Imagery Quick Terrain Modeler and Esri ArcGIS. The data was delivered to key stakeholders with ISO 19115-compliant metadata using secure ftp. JALBTCX also partnered with NOAA, as it has for NCMP, to provide the data through NOAA's Digital Coast web application.

> "(These datasets) help us understand where our vulnerabilities are and how the coastal system responds and give us a baseline for recovery so that we can better adapt, prepare and respond to future storm events."

In post-storm response mode, CZMIL data are delivered in a rolling fashion; that is, data collected on Day 1 are delivered on Day 3, Day 2 data are delivered on Day 4 and so on. It is not necessary to collect the entire project area to deliver final, classified point clouds that meet QL2 accuracy specification.

Looking ahead

Since Hurricane Matthew, there have been additional opportunities to utilize these processes and technologies to monitor and protect our nation's coastlines—as happened in early September 2017, when Hurricane Irma hit Florida. WMR-532 again supported JALBTCX in collecting data in the storm's path. The scale of Irma's impact was assessed by comparing immediate post-storm data to the previously collected data in order to conduct a coastal change analysis. The post-Irma data were collected for FEMA to determine eligibility of coastal communities to receive public assistance to reimburse installation of emergency protective measures.

We cannot predict where the next disaster will strike, but better preparation is well within our control. Jeff Lovin, Woolpert senior vice president and director of government solutions, said that by continuing to refine proven processes, protocols and technologies, the ability to respond and recover vastly improves.

"We created the joint venture as our primary objective is to support the widespread mapping needs of USACE and JALBTCX," said Lovin. "By enlisting WMR-532, JALBTCX gets the experienced flight crews, field support staff and data processing to support post-storm recovery efforts, and we will continue to apply the most effective resources toward that end."

John Gerhard is Vice President and Geospatial Program Director at Woolpert, based at the firm's Denver, Colorado, office. Gerhard earned his bachelor's degree in geography from Wright State University, is a Certified Photogrammetrist and a member of the American Society of Photogrammetry and Remote Sensing (ASPRS). He has worked at Woolpert for more than 29 years.

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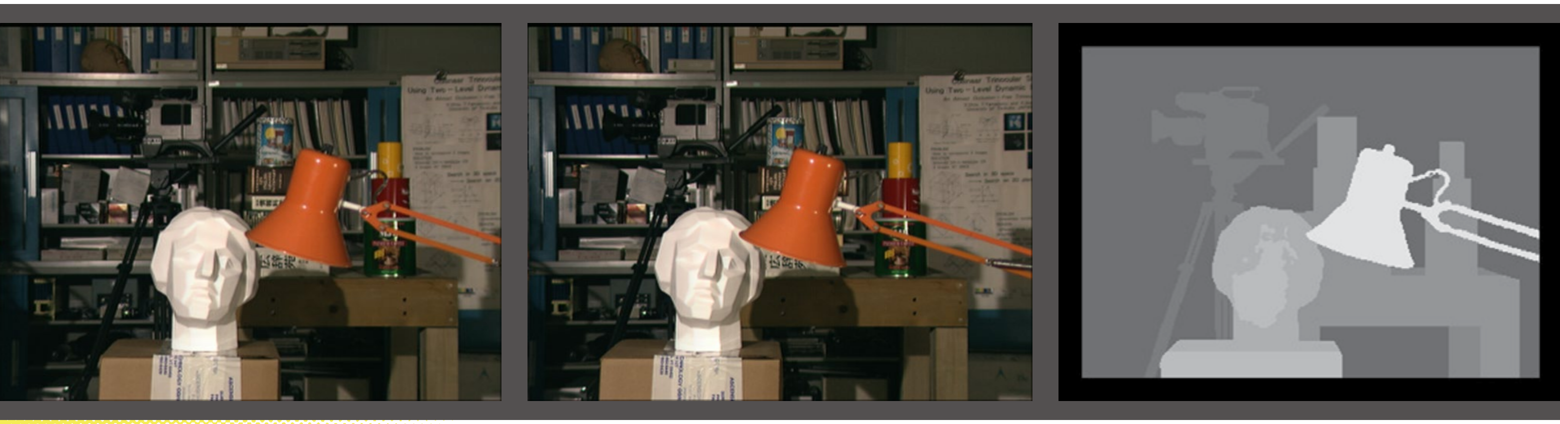

Figure 1: Left and right images of a stereo pair and the "disparity" map (right) showing the differences of each pixel in the right and left image.
(source: https://stackoverflow.com/questions/17607312/difference-between-disparity-map-and-disparity-image-in-stereo-matching)

EVOLUTION OF POINT CLOUD

BY SRINI **DHARMAPURI PHD, CP, PMP, GISP** & MIKE **TULLY, CP, GISP**

Wikipedia has defined a "Point Cloud" as a set of data points in some coordinate system. In a three-dimensional coordinate system, these points are usually defined by *X*, *Y*, and *Z* coordinates, and often are intended to represent the external surface of an object. Historically, point clouds have been created by active remote sensing scanners such as radar and Laser scanners that are used in aerial and terrestrial platforms. Laser scanners measure many points on an object's surface and often output a 3D point cloud as a data file.

Point cloud geometry is often known, rather mistakenly, as LiDAR. LiDAR is a technology for making point clouds, but not all point clouds are created using LiDAR. With the advent of Semi-Global Matching (SGM) and Structure from Motion methods (SfM), point clouds can be made from images obtained from digital cameras. In this paper, we will describe the concepts behind the point cloud obtained from active scanner and cameras. We will also study the characteristics of the data obtained from different laser scanners and imagery.

In general the quality of the point cloud obtained from LiDAR depends on scan frequency, point density, flying height etc.. The quality of point clouds created from the imagery using SGM or SfM are predominately affected by the ground sample distance (GSD), flight altitude and image content.

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In traditional photogrammetric methods, a point cloud is created using a manual stereo compilation process. Stereo compilation begins with digitizing 3D surface data at a regular interval from stereo imagery. These "mass points" are then supplemented with break lines at significant terrain changes such as ridges, summits, depressions, road edges and hydrographic features. With the advent of softcopy stereoplotters, some aspects of point cloud generation were augmented using autocorrelation techniques. These were an early form of computer vision that identified pixels within two or more images that were correlated with each other and then photogrammetrically assigned to those pixels horizontal and vertical coordinates. Because these methods require considerable manual labor, the point clouds are typically much sparser (1 ppsm or less) than those created from Lidar (2-100 ppsm), SGM (hundreds of ppsm), or SfM (hundreds of ppsm).

Semi-Global Matching or SGM is a recent technology developed in the field of computer vision to exploit digital camera systems.. The Semi Global Matching (SGM) stereo method is based on the idea of pixel-wise matching cost (disparity) of Mutual Information (MI) for compensating the radiometric differences of input images and uses a smoothness constraint. The core algorithm of SGM aggregates the matching costs under consideration of smoothness constraints (that is, an assumption that pixel values will change gradually as you move in any direction and they will likely be close in value to their neighbors). The minimum aggregated cost leads to the disparity map for a stereo pair (the disparity map shows the distance between two corresponding points in the left and right images of a stereo pair) and subsequently to textured 3D point clouds in object space. The large numbers of matches found in this way allow for the creation of very detailed 3D models. Basically, SGM provides the corresponding location (X,Y, and Z) for each image pixel and returns a point cloud with a point density approaching the GSD of the imagery.

SGM methods have several advantages over softcopy photogrammetry and autocorrelated point clouds. First, softcopy point clouds are typically computed using intensity values of each pixel. This causes several problems because the intensity of a feature in one image may vary due to sun angle, shadows, or reflections from the same feature in an adjacent image. In fact, many pixels cannot be matched to similar pixels in the adjacent imagery because of these intensity, reflection, and other differences. SGM, therefore, uses "mutual information" (i.e., a statistical measure of mutual dependence between two random variables (like pixel intensity) to correlate similar pixels between multiple images and is much more robust against varying intensities and reflections. Second, SGM is much faster than autocorrelation. This becomes a major advantage when processing thousands of very large images.

SFM, on the other hand, is computer vision technique based on the principles of photogrammetry wherein multiple overlapping, offset images are used to reconstruct a 3D point cloud of large complex scenes from a series of overlapping photos taken from different, overlapping positions. The SfM method uses a highly redundant bundle adjustment to reconstruct a sparse 3D point cloud of large complex scenes. The SfM approach computes simultaneously both this relative projection geometry and a set of sparse 3D points. To do this, it extracts corresponding image features from a series of overlapping photographs captured by a camera moving around the scene. SfM relies on algorithms that detect and describe local features for each image and then match those two-dimensional (2D) points throughout the multiple images. Using this set of matched points as input, SfM computes the position of those interest points in

> "The introduction of Semi Global Matching and Structure from Motion methods has opened up new vistas in the point cloud creation process."

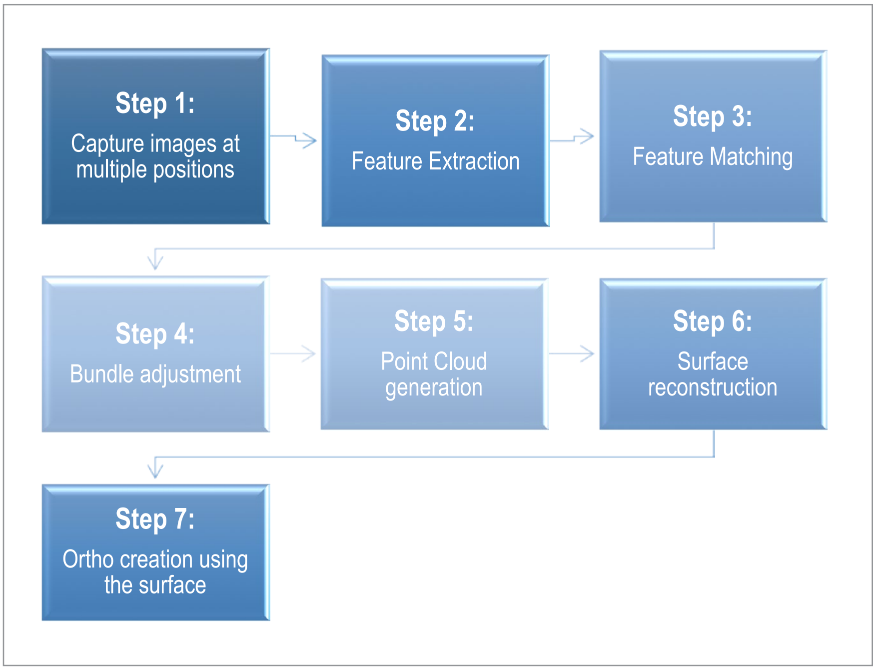


Figure 2: SFM Workflow

a local coordinate frame and produces a sparse 3D point cloud that represents the geometry or structure of the scene. As mentioned previously, the camera position and internal camera parameters are retrieved as well. Subsequently, the multi-view stereo is applied as the last stage by using the SfM result as an input to generate a dense 3D model. Multi-view stereo is the general term given to a group of techniques that use stereo correspondence as their main cue and use more than two images covering a single point.

In the SfM process (**Figure 2**), after the relevant photos are imported, the feature matching and relative photo alignment is performed. Tie points are detected based on a stable viewpoint and consistent lighting variations and generates the descriptor based on its local neighborhood. The descriptors are then used to align the overlapping photos leading to a sparse point cloud. Next, the initial camera locations are improved by using bundle adjustment algorithm based on the photos' Interior Orientation and Exterior Orientation parameters. Finally, the dense image matching points are constructed based on the multi-view algorithm. The last step is texture mapping by assigning the RGB values to each point.

How Traditional Photogrammetry, SfM and SGM Differ

Traditional photogrammetry relies on straight lines of overlapping imagery to produce point clouds. Surfaces are computed from two overlapping images. SfM allows for random images to be taken from varying angles and distances to create 3D geometry. As with traditional photogrammetry, to properly rectify the three-dimensionality of objects through a SfM approach, the objects must be present in multiple (3 or more) images. As more overlapping images are added, the result improves especially when using controls. Additionally, SfM uses the scale invariant feature transform (SIFT) algorithm that recognizes conjugate features (physical features) in multiple images despite dramatic differences in the image scale and viewpoint.

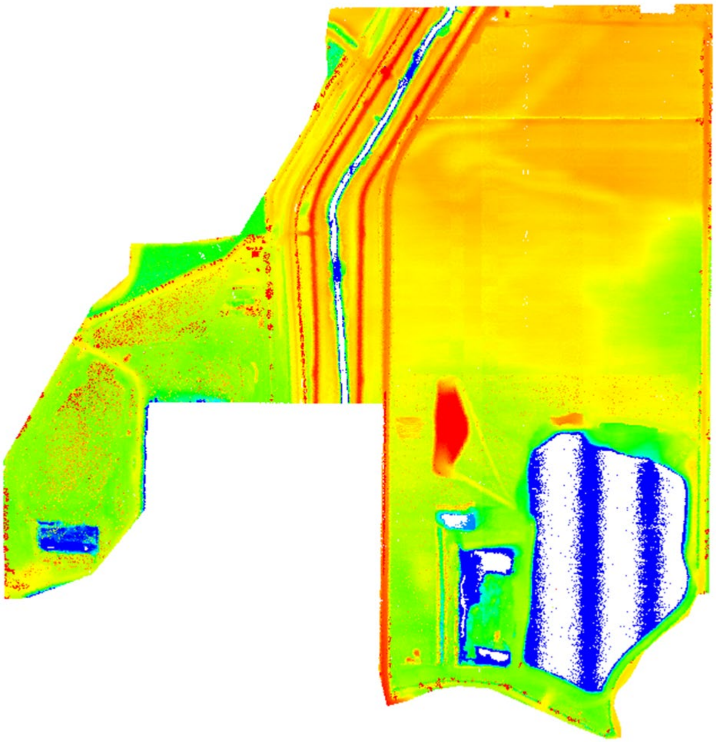
SfM is a technique to compute 3D surfaces from multi-view images. Additionally, SFM camera positions and orientation are solved automatically without the need to first specify a network of targets with known 3D positions. These are instead solved simultaneously using highly redundant, iterative bundle adjustment procedures that are based on a database of features automatically extracted from the overlapping imagery. Also, the simultaneous self-calibration of the camera's interior orientation parameters is performed in the process. An important property of SfM-derived point clouds is that they are not initially tied to real world space and orientation but rather to object space coordinates. The point cloud can be transformed to real world space by using a small number of known ground-control points (GCPs) that can be identified on multiple images. The SfM allows high-density point clouds of the first reflective surface (or the surface of features) to be rapidly and automatically extracted from stereo-imagery. In practice, it is not able to produce a point cloud for every pixel in the source imagery but only about every third pixel. SfM is a far more complex procedure that includes feature extraction, image matching, filtering, bundle adjustment (with or without control points),3D surface generation, and texture mapping.

SGM is a pixel-wise matching algorithm that is robust and can preserve edges. The original algorithm performs matching with stereo images (just two) in contrast to multiple-view images in SfM. However, there are variants to SGM that can handle multiple-view images. These variants typically perform matching with all possible stereo images and combine the results to create a final result. Hence, SGM can be used in SfM to generate dense point clouds.

Comparison of LiDAR and Imagery-based point cloud

The LiDAR and Imagery-based (photogrammetric) point clouds are similar because they consist of a point cloud containing 3D data points. The imagery-derived point cloud is typically output in LAS format and is processed much like LiDAR data. This point cloud can be further enriched (or “textured”) by assigning RGB and IR information contained in the imagery to each data point. In fact, if 4-band imagery is processed, it is possible to attach an Normalized Difference Vegetation Index (NDVI) value to each point.

While the photogrammetric-derived point cloud is comparable to one created by LiDAR, there are a few



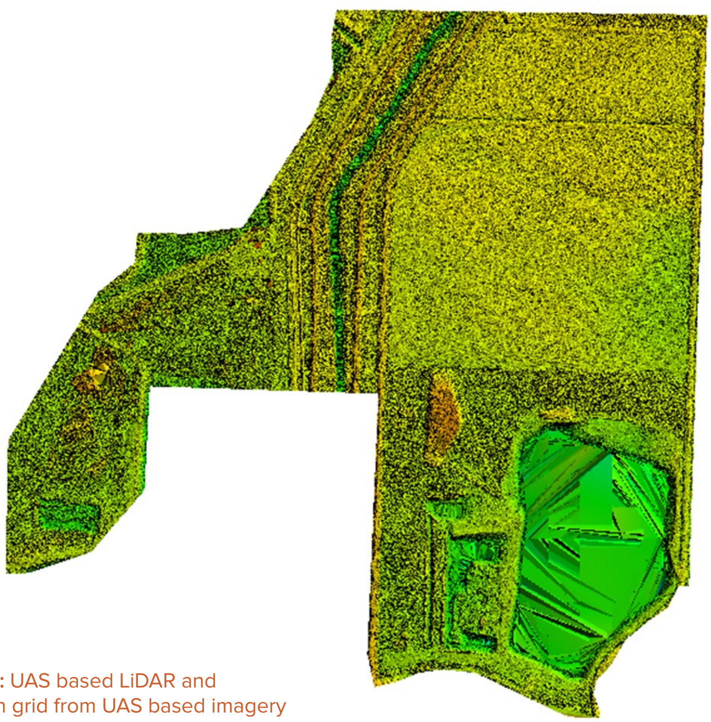


Figure 3: UAS based LiDAR and Elevation grid from UAS based imagery

significant differences. A 3D point cannot be derived to a image pixel unless the same pixel is "found" in a second or third or N overlapping images. Imagery that contains scenes with very uniform texture (like fields of grass or corn, dense forest canopies, blacktop parking lots, dark shadows, etc.) cannot be modeled because the algorithms are unable to identify one pixel as distinct from adjacent pixels in one or overlapping images. These areas are often referred to as "texture-less" areas. The net result is that in "texture-less" areas, the point cloud will contain a void of points. However, because LiDAR is an "active" sensor (that is it emits light) and reflects off features (ground or surfaces), the texture of a scene much less frequently inhibits modelling of that area. Another strength of LiDAR is that each reflected point is returned with a precise coordinate location (X, Y, and Z) and does not require a second or third point reflected from the same object in additional overlapping images to determine its precise location.

Another type of limitation of points derived by photogrammetric means (SfM, SGM, traditional photogrammetry) is that they will model only the first returns or "surface features". Points collected from LiDAR, on the other hand, can provide multiple returns, that is, the first return or surface of features, but also the surfaces under and within vegetation canopies. The authoritative information about the ground captured under canopies by LiDAR enables the creation of additional products like contours. Creation of an accurate ground surface model and contours in thick forested areas from the photogrammetric (SFM, SGM) point cloud is difficult or impossible because only the visible surface is modelled.

> "These evolving mapping technologies that use imagery only to generate 3D point clouds are tools of growing importance for the mapping profession that gives professionals more flexibility in meeting project objectives."

Another difference of LiDAR data is that it is directly measured, that is, light is emitted, and its reflection is sampled. LiDAR is not subject to potential issues associated with photo quality and photo processing that can affect the quality and accuracy of the vertical component of vertical points derived using the other methods.

Recently an exercise has been performed in which data was collected using conventional LiDAR, UAS LiDAR, UAS (fixed wing, multi rotor) and the point cloud derived from sensors were analyzed for their characteristics. **Figure 3** shows the LAS data obtained from UAS based LiDAR and UAS based imagery. In part 2 of this series, we will discuss important aspects of point clouds acquired from UAS and manned platforms and by photogrammetric and Lidar means.

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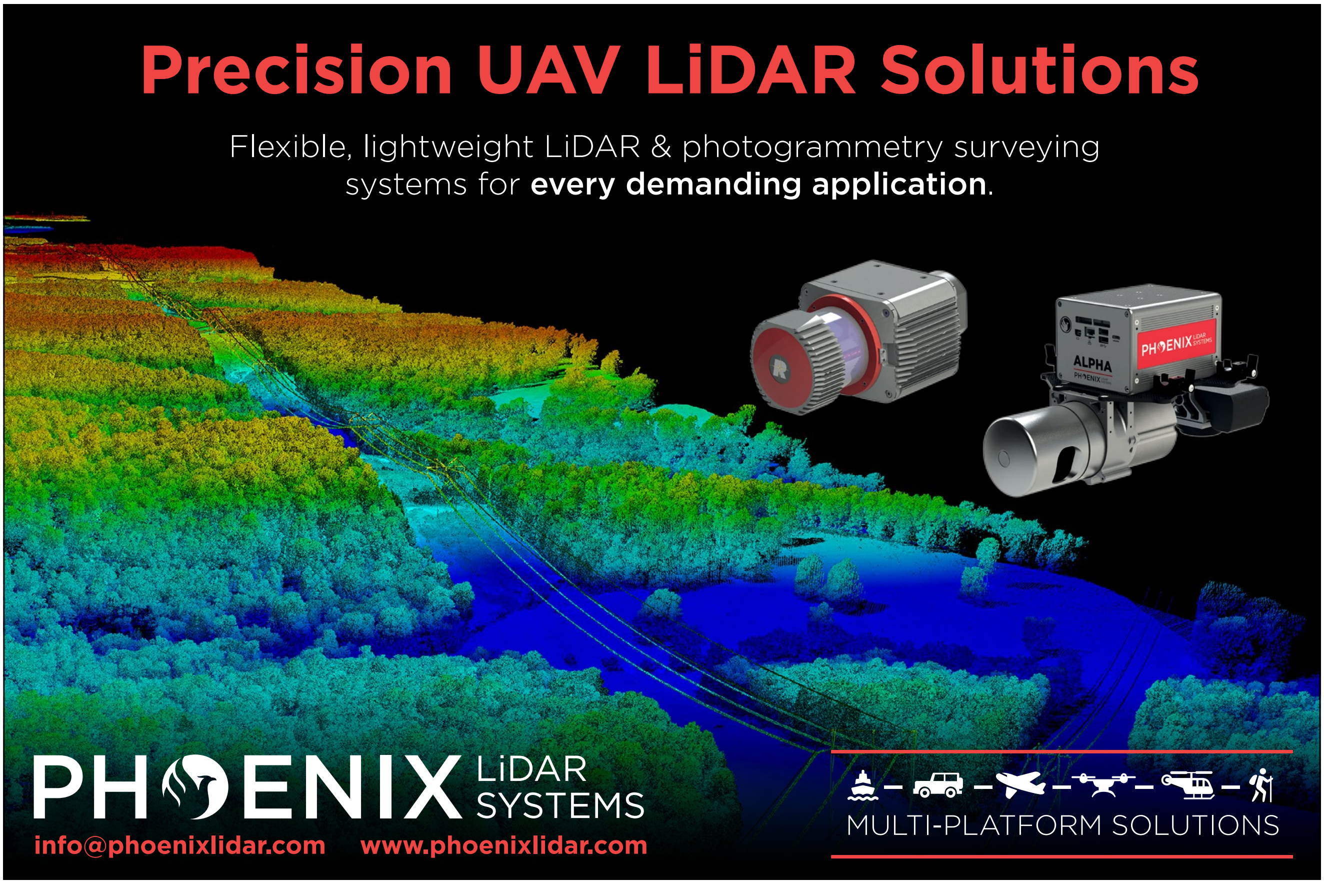
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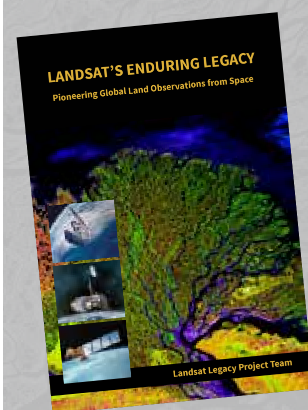
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MOBILE MAPPING REDUCES COSTS, INCREASES EFFICIENCY

When mobile mapping solutions were introduced in the year 2000, the city of Amsterdam saw many uses for the 360-degree geo-referenced images. Mobile mapping gave a better view of the state of the built environment than aerial imagery by providing a different angle and higher detail.

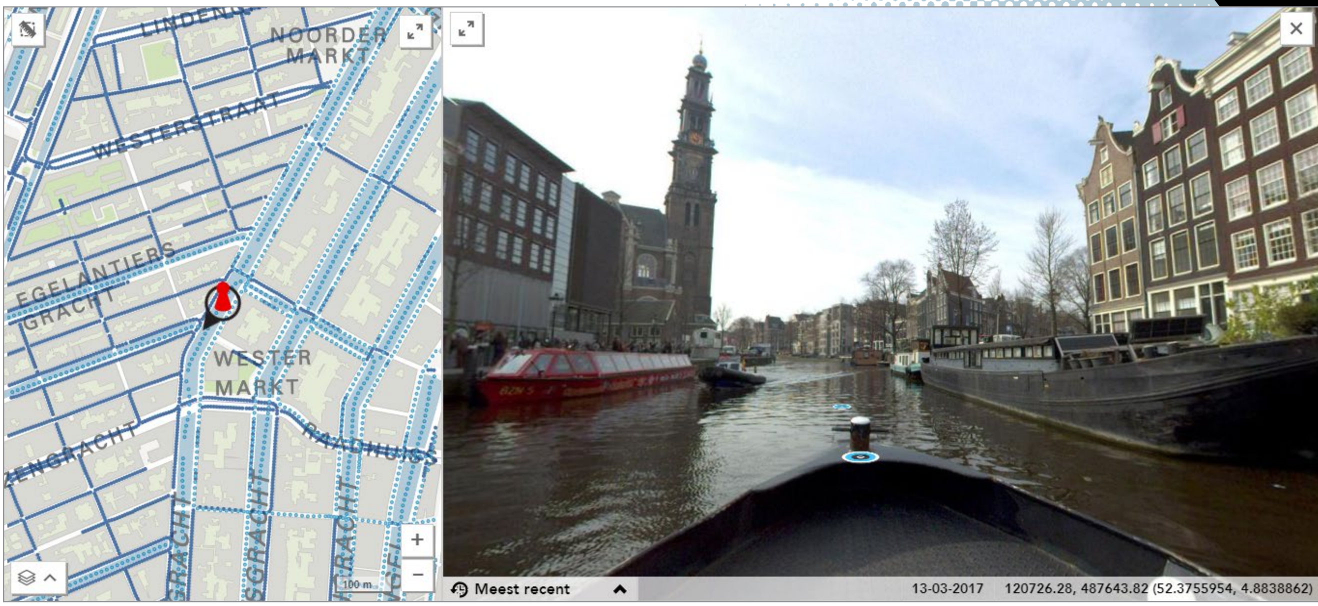
The city initially outsourced the imaging, which resulted in high costs and limited usage and update possibilities. To eliminate these issues, they purchased their own mobile mapping system.

Providing Value for Taxpayers

Prior to purchasing the in-house system, the Dutch Cadaster commissioned a contractor to collect nation-wide street level imagery. Amsterdam would license part of that material for its own use. Over time, the city became dissatisfied with the contractor´s working methods. "To me, it seemed exploitive to grow a business by making governmental agencies use tax money to pay for the same product over and over again. Paying

Amsterdam's mobile mapping vehicle enables cost-efficient data acquisition and frequent updates.

BY ERIC VAN REES



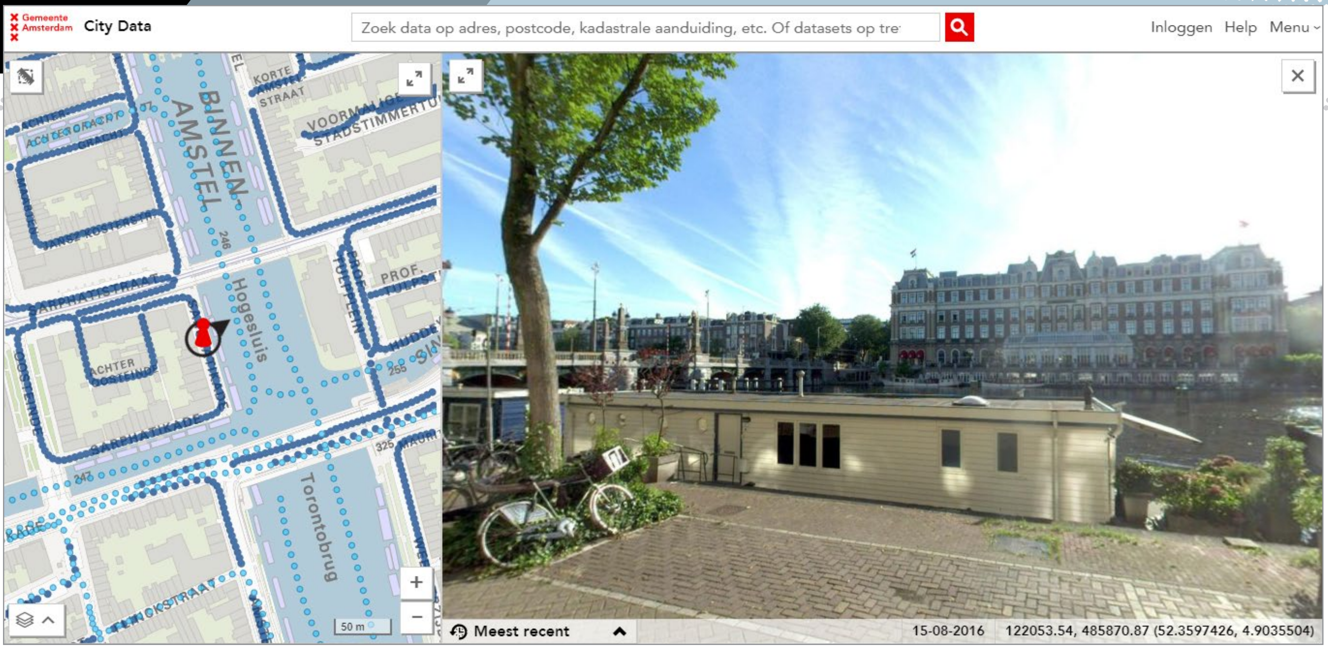
Amsterdam mounts its MX7 on a boat to capture data in the city's canals.

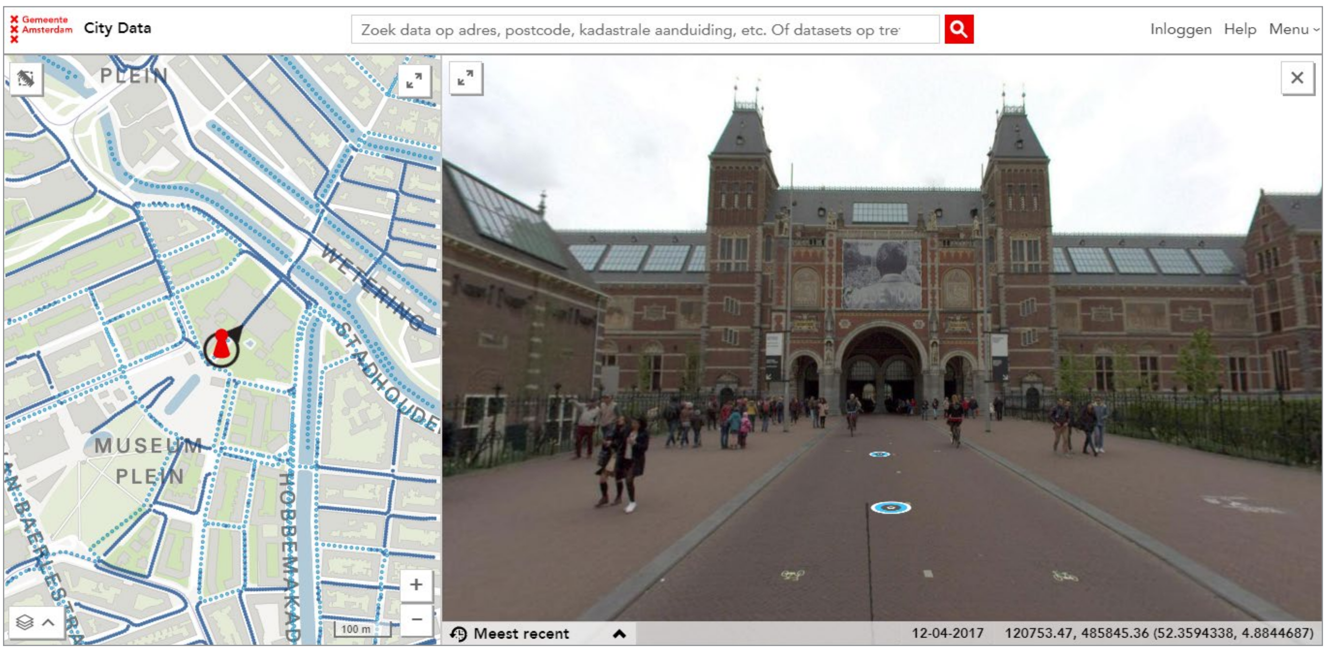
> “By owning its own system, Amsterdam can capture the entire city twice a year, instead of just once a year as they did with the contractor.”

for the data collection with tax money is one thing, but doing the same for each separate use is simply too much,“ said Ries Visser, Senior Advisor, Basic Information at the city of Amsterdam.

Using a contractor for the imagery also meant abiding by strict terms of use, as well as limited flexibility in choosing when the data was captured. “We´d receive a timeslot for the coming two months from the contractor. If the

One person can drive the car and operate the mapping system. The mapping project enabled Amsterdam to hire new employees.





Amsterdam's mobile mapping system produces georeferenced street views accessible to the public via web-based GIS technology. Information can be updated twice per year.

weather was bad during that time, it would show on the street level imagery, diminishing its usability," Visser said. The city wanted more flexibility.

Bringing Mobile Mapping In-house

To be more independent and to have more control over the imagery, the city of Amsterdam decided in 2016 to acquire an in-house mobile mapping system. After extensive market research, they chose the Trimble MX7 Mobile Mapping Imaging System, making Amsterdam the first worldwide user of the system. Amsterdam selected the MX7 because it provided a single integrated system that was easy to mount on a car; it could also be used on water, critical for the elaborately canaled city. They also wanted an open system so third-party vendors as well as single viewers could access the imagery.

The city uses Trimble POSpac Mobile Mapping Suite and Trimble Business Center (TBC) Survey CAD software for the workflow. The POSpac Mobile Mapping software is used for georeferencing the imagery, whereas TBC helps deliver high-accuracy GNSS data. After processing, the data is copied to a server and recognizable faces are automatically blurred. The imagery is published and shared with external users through a web application. Having its own mobile mapping system meant that the city of Amsterdam could capture street view imagery anytime, anyplace and share it with any stakeholder inside the organization. This was important because many departments rely on the imagery for their daily work.

The city hired three drivers to capture the imagery as part of a corporate social responsibility initiative subsidized by the city of Amsterdam. This created jobs and reduced expenses since operating the system doesn't require technical skills. By outsourcing the collection work, Amsterdam provided employment to the unemployed.

More Flexibility, Higher Efficiency and More Updates Per Year

To increase efficiency, the MX7 is used almost daily. The system can be mounted on a boat to navigate Amsterdam's famous canals, which allows the city to monitor the quays and see where maintenance might be necessary. The system is also mounted on a Port of Amsterdam boat to monitor the port.

By owning its own system, Amsterdam can capture the entire city twice a year, instead of just once a year as they did with the contractor. Updating the imagery often is necessary as the city changes rapidly. Having panoramic imagery that provides a recent view of the city is important so firefighters and ambulance drivers can view the surroundings before they arrive, enabling them to act faster.

In addition, having an in-house mobile mapping system saves taxpayer money. Panoramic imagery is captured once and used multiple times. The concept of open data is very important to the city, says Visser. "The imagery is paid with tax money, and we think citizens are as much owner of the imagery as we are. This is why the imagery is accessible to everyone through our web portal."

The city of Amsterdam is a pioneer in mobile mapping, and other Dutch cities have expressed interest in trying it. When Amsterdam is not capturing images with the MX7, they share it with nearby suburban districts, which put it to good use.

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The MX7 system installed in a vehicle. The hardware is readily transferred to other vehicles or boats.

***Graham,** continued from page 48*

unit of length, the meter (or metre if you are not in the USA!). In 1793 the meter was defined to be one ten-millionth the distance from the equator to the North Pole along a meridian passing, of course, through Paris. The impracticality of this was quickly realized and it was redefined in terms of a platinum reference bar ("mètre des Archives") in 1799.

The definition of the meter was not the clever bit. The first good piece of thinking was to define all super and sub units as powers of ten (a decimal system)—none of this nonsense of 16 ounces to a pound, 12 inches to a foot and so forth. That makes it very easy to remember as well as to do quick estimates. One would think this as completely obvious but here in the good old USA we still use yards, feet and inches, none of which are rational relative to one another!

The really clever bit was to base the units of volume and weight on water and the meter. The kilogram was, by definition, the mass of a cube of water (the water being at standard pressure and the temperature of maximum density, about 4 C) where the cube was 1/10 of a meter on edge. This leads immediately to the Centimeter-Gram-Second (CGS) definition of a milliliter being the volume of a cube exactly 1 cm on edge and the gram being the mass of water that occupies that cube (see **Figure 1**). Even though, in the US system, a fluid ounce is approximately 1 ounce weight, the system falls apart when you hit cups, pints and pounds.

Because of this very clever original definition of the metric system, it is a piece of cake to make estimations in your head. All you need to remember is the density of whatever you are estimating. Of course, quite often it is water where the density is one (or certainly close enough for estimations). Want to know the mass of a 1 liter bottle of soda pop? Well, soda is essentially water so it's 1 kilogram. We are keenly interested in estimating weight in aircraft systems when discussing fuel loads. Jet A-1 fuel has a density of about 800 grams per liter (actually 804 but the 800 number is good enough for estimations). If I load 1,000 liters of fuel, I have a mass of 800 kg. Estimating tank volumes in terms of liquid measure is direct; just compute the volume in cubic centimeters and you have the fluid volume in milliliters. At a deeper level, the metric system is a *rationalized* system of measure. Basically, this means that derived units such as those of energy and electromagnetism require no artificial constants in their defining equations. This is beautiful in its simplicity and lucidity.

So what does all this have to do with point cloud formats? Actually, nothing at all. My hope is simply that we can apply some of the exceptionally clever thought processes of the original design of the metric system to any new definition on which the industry embarks. It's unlikely that any of the nice relations of powers of ten and deriving from the unit of length apply directly but the very rational thought process should most definitely be a guiding principal. Here's to cubic thinking!!

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Metrically Thinking

OK, this article, in keeping with the column title, is truly a Random Point!

There has been a lot of talk lately about developing a new standard for point cloud data (mostly for LIDAR and dense image matching, DIM). The Open Geospatial Consortium (OGC) recently announced a position of supporting emerging and existing community standards rather than pursuing a standard of their own. This position was probably taken because point clouds have reached the level of maturity that no one standard will satisfy everyone. Other groups, meanwhile, are plowing ahead with a replacement for the ubiquitous LAS format. I personally am hoping something very clever emerges that still retains a few of the LAS features that have made the format so successful.

There is a lot wrong with LAS (just like there is a lot wrong with the de factor vector format, Shape) but a few things have stood the test of time. The first is the very simple idea of making LAS a rectangular cuboid container. This decision led to projects being naturally tiled, providing the first level of indexing for a rapid access data management system. I find it quite interesting that after 20 years of trying to develop point storage databases, the file-based rectangular cuboid dominates all main stream access systems. As far as I know, all very high-performance streaming display systems today are based on some variant of an octree which is, of course, a rectangular cuboid system.

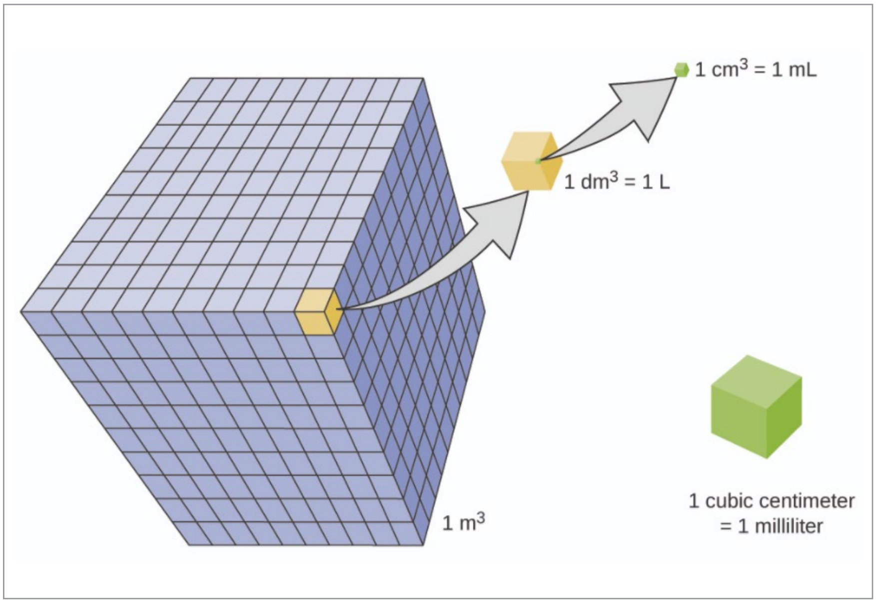

Figure 1: The metric system as a cube

The second thing we did right when developing the very first iteration of LAS was to make the point representation integers rather than floating point numbers. This was a very deliberate decision even though it poses some extra overhead on storage and retrieval. At the time of the original design, it was still common practice for anyone writing computer software to be well-versed in numerical analysis (something that I fear may be disappearing from modern curricula). A student of Hamming's "Numerical Methods for Scientists and Engineers" (a book which is fully relevant to this day) knows the logarithmic resolution problem with floating point numbers in computers. The scaled and offset integers of LAS coordinates circumvent this problem. So now some thoughts on reinventing…

Some folks count sheep when they cannot sleep. I tend to try to do some sort of mathematical estimation problem (I know; very strange and it does more to keep you awake than to induce sleep). I was recently trying to estimate some relationships between weight and size which led me to think about the beauty of the original design (during the French Revolution) of the metric system. The core of the system was the

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