LIDAR MAGAZINE

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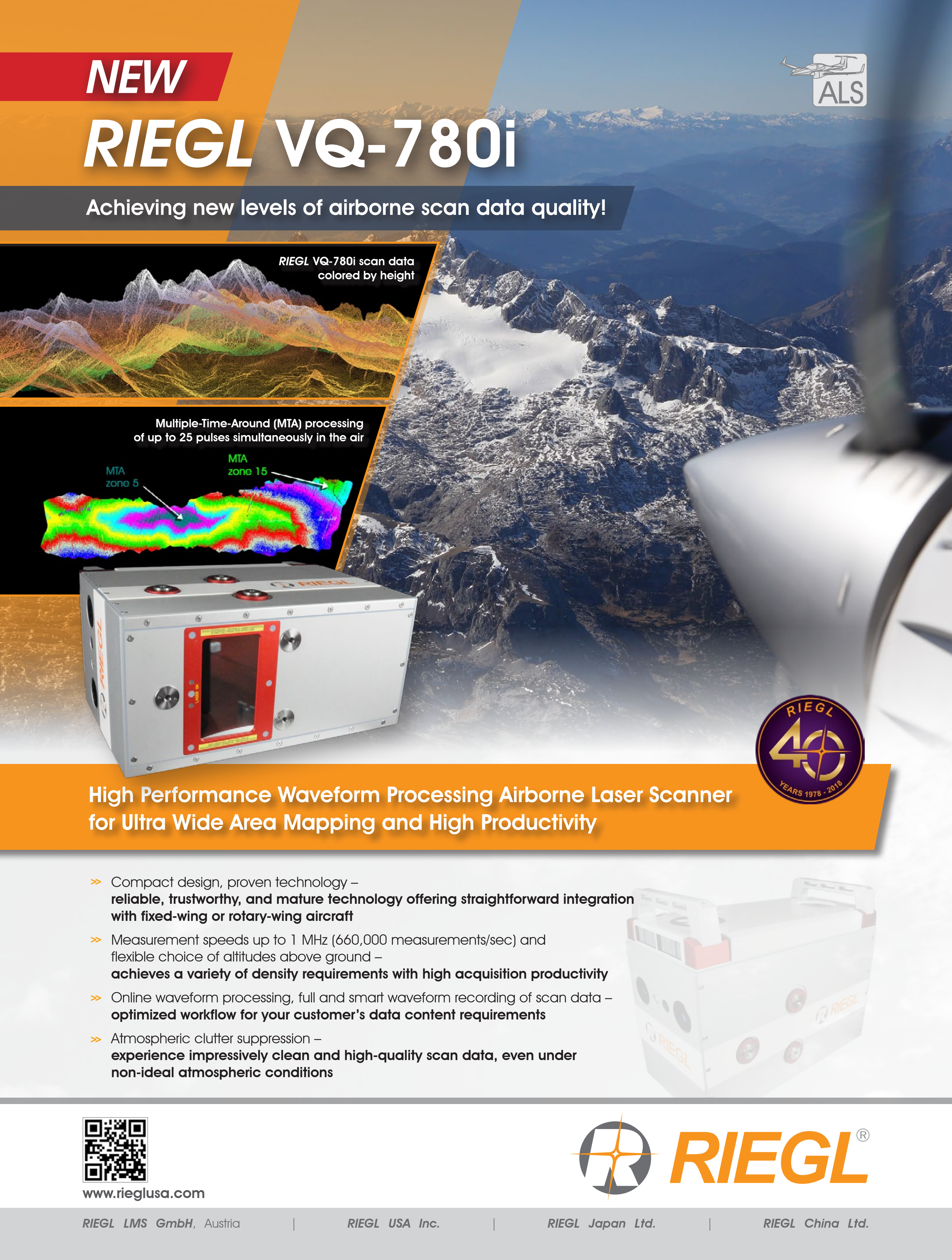
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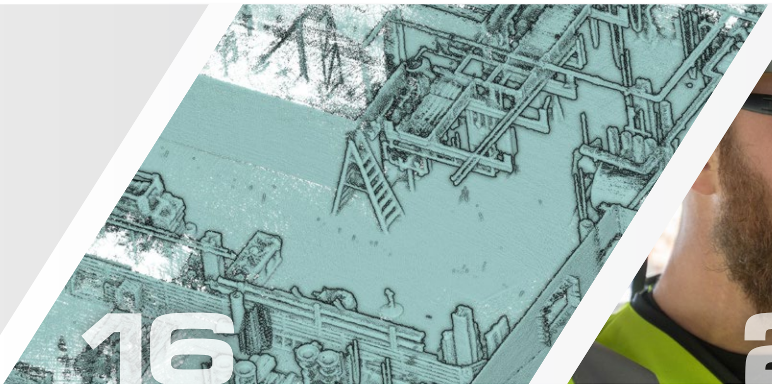

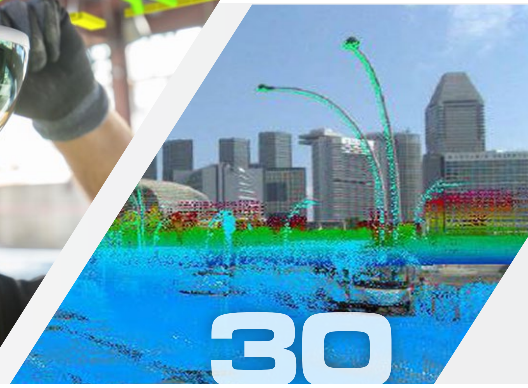

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View of the grand plaza of the Maya city of Tikal in Guatemala. Initially, a 3D first-surface model was overlaid with a false-color multispectral lidar intensity image. Removal of lidar returns that originated from vegetation reveals human-made structures and topographic modification by the Maya.

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FROM THE EDITOR

DR. A. STEWART WALKER

Lidar, On the Road Again

In fulfillment of its responsibility to bring readers the most compelling, varied and relevant articles possible, LIDAR Magazine attends conferences and exhibitions throughout the year, not only to keep up to date with the industry and the profession, but also to meet and converse with prospective contributors. We have enjoyed unexpected, fascinating discussions and in some cases these will turn into articles. This year, our group plans to attend more than fifteen significant geospatial events—if you're going to one, chances are we are too, providing a chance to meet up.

Sadly, we had to miss the YellowScan LiDAR for Drone 2019 user conference, which took place late March in Montpelier, France, attracting many customers of this well established UAV-lidar integrator; our very own Lewis Graham delivered the keynote. I must also mention the user conference of nFrames, the Stuttgart start-up that offers world-leading software for generating point clouds and derived products from imagery and has recently added lidar capabilities.

> "Geo Week attendance was 1682 from all 50 U.S. states and 33 countries. The sold-out exhibition hall was packed with 104 exhibiting companies, 21 organizations exhibiting at ILMF for the first time."

2019 started with Geo Week in Denver. Though this was more than two months ago, it remains etched in our memories for two reasons: its success; and the presentation, for the second time, of the LiDAR Leader Awards. Our partner in the LiDAR Leader Awards, Diversified Communications, announced that the attendance had been 1,682 from all 50 U.S. states and 33 countries. Of those in attendance, 53% were attending the event for the first time. The International LiDAR Mapping Forum (ILMF) 2019 took place as part of the inaugural edition of Geo Week along with the MAPPS Winter Conference and the American Society for Photogrammetry and Remote Sensing (ASPRS) Annual Conference. Last year, ILMF and the ASPRS Annual Conference took place together for the

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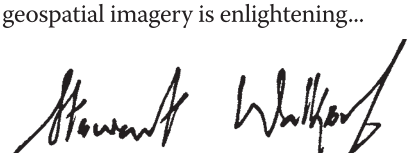
first time while the MAPPS Winter Conference took place separately. The co-located events maintained their own technical programs but shared a single combined exhibit hall. By uniting all three events for the first time, geospatial professionals gained access to more geospatial solutions, technical education, and networking opportunities than ever before. All this happened despite the government shutdown severely impacting attendance by

> "The use of lidar by the Scripps Institute of Oceanography to measure rising sea level made local TV news in San Diego."

professionals from agencies such as USGS. The co-location of MAPPS was significant: for Geo Week to receive this influential body's imprimatur is no small matter; moreover, the presence of senior managers from MAPPS member firms added gravitas to the event and enlarged participation in the exhibition and technical sessions. Indeed, the sold-out exhibit hall was packed with 104 exhibiting companies showcasing best-in-class geospatial technology solutions. Among the exhibitors were 21 organizations exhibiting at ILMF for the first time. Next year's event will be held March 23-25, 2020, at the Walter E. Washington Convention Center, and we can be sure Diversified Communications will try its best to involve even more organizations of geospatial professionals.

It was a huge privilege to co-host the LiDAR Leader Awards ceremony with Lisa Murray of DivCom and honor the winners. Further details are given in our highlight of this year's recipients on pages 6-7.

Once again, I've come across more interesting articles. The use of lidar by the Scripps Institute of Oceanography to measure rising sea level made our local TV news in San Diego: kpbs.org/news/2019/jan/29/scientists-study-imperial-beach-sea-level-rises/. In the background during an interview with Dr. Mark Merrifield is the RIEGL VZ-2000 used to survey the beach and incoming breakers. And this month's two pieces from *The Economist* are both related to Israel. The first described aerospace engineer Abe Karem[1], who came to the US from Israel in 1977 and began work in his garage to create operational UAVs. His company, Leading Systems eventually became part of General Atomics. He could scarcely have foretold the effect UAVs are having on today's lidar! The second reports that the Israeli precision agriculture world has discovered that people who had previously worked as image analysts in the Israeli military were particularly well suited to becoming tech entrepreneurs[2]. Looking at geospatial imagery is enlightening...



A. Stewart Walker // Managing Editor

1 Anon, 2012. The dronefather, *The Economist Technology Quarterly*, December 1 2012, 23-24.
2 Anon, 2019. Agritech in Israel: silicon makes the desert bloom, *The Economist*, 430(9125): 41, 12 January.

AND THE WINNERS ARE...

LIDAR
LEADER AWARDS
BROUGHT TO YOU BY
ILMF & LIDAR MAGAZINE

Earlier this year, the second annual Lidar Leader Awards ceremony was held at International LiDAR Mapping Forum (ILMF) in Denver. In cooperation with the organizers of ILMF, we designed this unique program to recognize excellence in five distinct categories:

- Outstanding Personal Achievement in Lidar
- Outstanding Team Achievement in Lidar
- Outstanding Enterprise Achievement
- Outstanding Innovation in Lidar
- Outstanding University Achievement in Lidar

Lisa Murray, Group Director at Diversified Communications stated of the awards, "We were delighted to host the second annual Lidar Leader Awards at International LiDAR Mapping Forum. We started this awards series to recognize excellence in the industry and to highlight some of the amazing projects that were being presented on our program. The lidar community has enthusiastically embraced the process, nominating over 70 individual and teams for awards this year. In the spirit of the inaugural Geo Week co-location of ILMF, ASPRS and MAPPS, we shared the stage with ASPRS to present four of their prestigious industry awards. Kudos to all the winners. We look forward to recognizing your amazing contributions for many years to come."

Dr. A. Stewart Walker, Managing Editor at Lidar Magazine agreed. "This is the second year of the Lidar Leader Awards and, during the nomination period, we hoped very much that the entries would maintain the remarkable quality that we enjoyed last year. We were not disappointed. The quality was very high indeed. We introduced two new categories this year, Outstanding Innovation in Lidar and Outstanding University Achievement in Lidar, to honor accomplishments that perhaps were not ideal fits for the three categories with which we began the awards last year. Both categories drew fine candidates and those who attended the University Lightning Round doubtless feel delighted at the talent of the next generation of lidar movers and shakers."

2019 LIDAR Leader Award Recipients

Outstanding Personal Achievement

Karl Heidemann, Physical Scientist, USGS (Retired)

Hans (Karl) Heidemann, former Physical Scientist at the USGS EROS Center, was recognized for his Outstanding Personal Achievements in the industry. Heidemann led the development of lidar standards and specifications within USGS. He was heavily involved with the National Elevation Dataset, the National Geospatial Program and the 3D Elevation Program (3DEP), and authored three releases of the USGS Lidar Base Specifications (LBS). He was a co-author of the ASPRS Positional Accuracy Standards for Digital Geospatial Data and established the ASPRS standard for the number of lidar QA/QC checkpoints in vegetated and non-vegetated terrain. He is a long-standing, active member of ASPRS, serving on numerous committees, instructing in workshops and contributing to publications.

Outstanding Team Achievement *(2-99 Members)*

Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) Team

The Outstanding Team Achievement in Lidar was awarded to the Joint Airborne Lidar Bathymetry Center of Expertise (JALBTCX) Team for their efforts in acquiring airborne lidar bathymetry multiple times along the United States coastline as well as in Alaska, Hawaii and the U.S. territories. Additionally, the team acquired emergency response data following natural disasters such as Katrina, Sandy, Matthew, Irma, Maria and Florence. The data is used to analyze beach and dune response to storms, assess shoreline changes and support coastal resiliency. The efforts of the JALBTCX team continue to advance airborne lidar bathymetry and coastal mapping technology to greatly benefit the mapping industry.

Outstanding Enterprise Achievement *(100+ Members)*

Woolpert

Winning the Outstanding Enterprise Achievement Award was Woolpert, for providing many high-level contributions to the lidar industry in service, management and development ever since lidar technology was introduced. A sample of Woolpert's accomplishments include: working with USGS to acquire and process over 350,000 square miles of lidar data in support of the 3DEP program; evaluating and improving data workflow, that led the design, integration and testing of BuckEye's next-generation airborne sensor; and supporting US Army Corps of Engineers/JALBTCX' bathymetric and topographic lidar acquisition.

Outstanding Innovation in lidar

AEye for the AE110 Artificial Perception System

New this year, AEye was the first to take home the Outstanding Innovation in Lidar award for the creation of the AE110 Artificial Perception System. The AE110 is a solid-state artificial perception system that takes a disruptive approach to vehicle perception. Its distributed system fuses solid-state agile lidar with a low-light HD camera, then integrates artificial intelligence to capture more intelligent information with less data. By using a distributed, software-definable system that embeds computer vision with machine and deep learning on its lidar, the AE110 puts perception engineers in control and brings intelligence to the sensor layer, which enables the type of precision and real-time perception that is critical to the rollout of safe autonomous vehicle systems.

Outstanding University Achievement *(Three Categories)*

A. Albright—University of Houston

(Most Innovative Use)

Hasso Plattner Institut

(Most Commercially Feasible) +
(People's Choice Award)

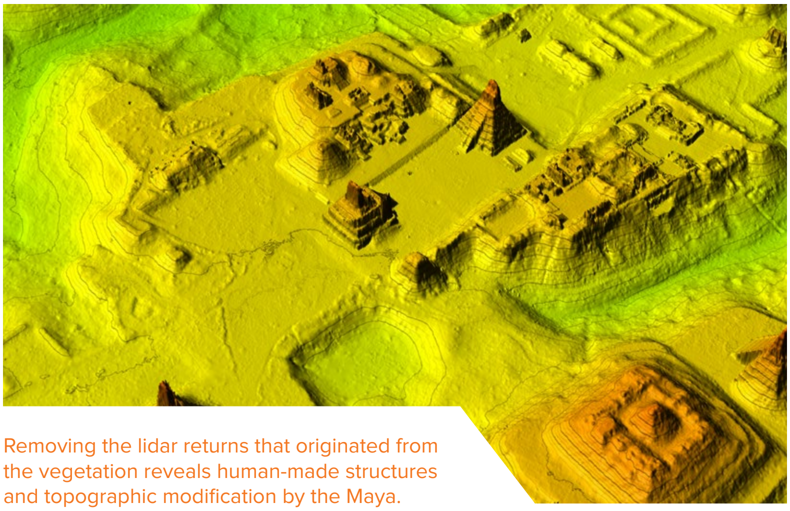
The Outstanding University Achievement in Lidar category awarded three winners this year following the University Lightning Round took place yesterday which took place on Monday, January 28. Participants of the Lightning Round were judged on awards up for grabs in three categories, including: 1) Most commercially feasible; 2) Most innovative use of lidar; and 3) People's Choice. Soeren Discher and Rico Richter of Hasso Plattner Institut took home the most commercially feasible award, delivering a presentation on the value of point clouds: solutions for management, analysis and presentation. Andrea Albright of University of Houston won the most innovative use of lidar award with an impressive presentation on measuring breaking waves using lidar technology. Finally, the crowd voted on the People's Choice award, again awarding it to Hasso Plattner Institute. Each university gave remarkable presentations to an audience of geospatial and academia professionals alike.

ILMF and *Lidar Magazine* are excited to continue celebrating excellence in 2020 and for years to come and congratulate all the nominees and winners for their work in advancing lidar.

Airborne Lidar for Archaeology in Central and South America

Teledyne Optech sensors map ancient civilizations under the rainforest

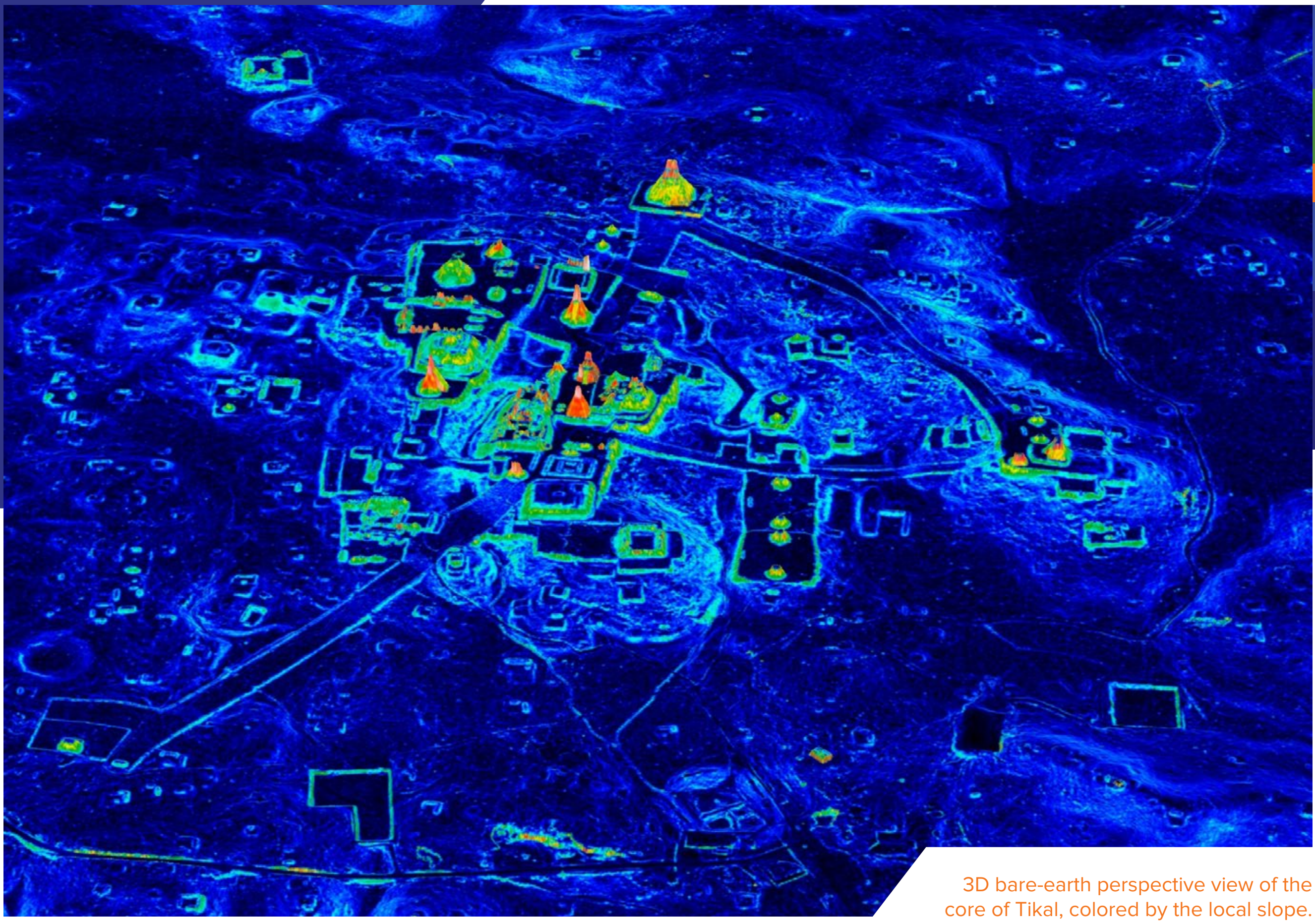
Multispectral lidar view of the grand plaza of the Maya city of Tikal in Guatemala. The 3D first-surface model was overlaid with a false-color multispectral lidar intensity image.



Removing the lidar returns that originated from the vegetation reveals human-made structures and topographic modification by the Maya.

The rainforests in Central and South America give little indication of the civilizations that they've swallowed up. A few centuries ago these regions were home to bustling indigenous cities, yet when the civilizations collapsed or the settlements were abandoned, the forests quickly overran their buildings like a rolling green carpet. Now, we can see little of these structures except for the occasional pyramid poking out of the forest to indicate the location of what was once a sprawling metropolis. These forests

BY ANDREW **MOLLER** & DR. JUAN C. **FERNANDEZ-DIAZ**



3D bare-earth perspective view of the core of Tikal, colored by the local slope.

have made it difficult for archaeologists to study the cities and the cultures that made them. Thankfully, the last two decades have given archaeologists an important new tool: airborne lidar.

Flying above the forest on an aircraft, lidar systems emit laser pulses to measure the elevation of the ground below and create detailed 3D maps of the terrain. This approach is significantly more productive and even more detailed than trying to survey from the ground. For example, at the Maya site of Caracol in Belize, it took archaeologists 20 years on foot to survey just nine square kilometers. Using airborne lidar, 200 square kilometers were mapped in as little as six days, with greater resolution than that accomplished on foot.

Oblique aerial photo of the Caana (sky-palace) pyramid at the Maya site of Caracol in Belize.

While ground surveys are ideal for documenting localized site details, airborne surveying provides the surveyor a much broader, yet detailed, perspective of the area. A walker may encounter a slight ridge in the earth and think nothing of it, but a lidar's overhead view can identify that the ridge extends in a straight line for hundreds of meters and connects to other features.

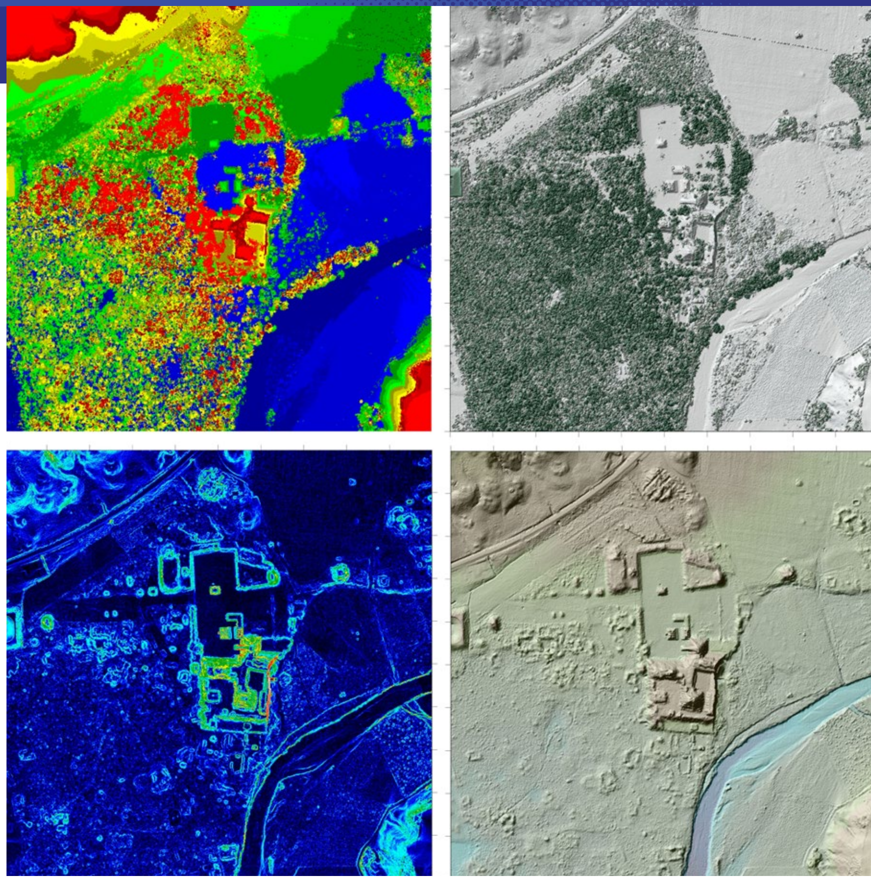
The first commercial lidar sensors became available in the mid-1990s. Unlike traditional photographic sensors, airborne lidar had the unique capability to be used day or night, penetrate vegetation canopies and map underlying structures. Since then, significant improvements in technology have resulted in lidar becoming an essential exploratory tool for archaeologists worldwide. This article describes some of the key advances in airborne lidar sensors and how they have helped us map out the civilizations that once thrived centuries ago.

Humble beginnings

The earliest use of lidar for archaeological purposes in South and Central America was almost serendipitous. In response to the devastation caused by Hurricane Mitch in Honduras in 1998, the Bureau of Economic Geology at the University of Texas used its then-new Optech ALTM 1225 airborne lidar in 2000 to derive accurate topographic maps that the United States Geological Survey (USGS) could develop into flood risk maps. As a side project, the Bureau wanted to collect some sample data to try different approaches to ground classification, and decided to do so at the nearby Maya site of Copan in western Honduras.

The ALTM 1225 was uniquely equipped for surveying in the rainforest. When a lidar fires its laser at a forest, some of the beam hits the thick canopy, some hits the lower branches, some hits the undergrowth, and finally (if the researcher is lucky) some of it reaches the forest floor. The lidar receives a distinct return pulse for each of these objects, but early lidar models recorded only the first return from the canopy for each laser pulse, which wasn't very helpful for determining what was on the forest floor. By comparison, the ALTM 1225 had a capability, new at the time, to record both the first and the last return reflections. With careful data processing, the users could strip away the first returns from the canopy so that only the ones from the ground remained, giving them a view of the bare earth below.

It is this ability that makes airborne lidar stand out from other wide-area surveying techniques such as photography and synthetic-aperture radar (SAR). Both of these techniques have their place in archaeology, but neither of them can easily penetrate through heavy canopies to survey the ground underneath. In Copan, the ALTM 1225 proved that airborne lidar could do what photography and SAR couldn't: look through the rainforest at high resolution and bring to light the ruins that it's been hiding for centuries.

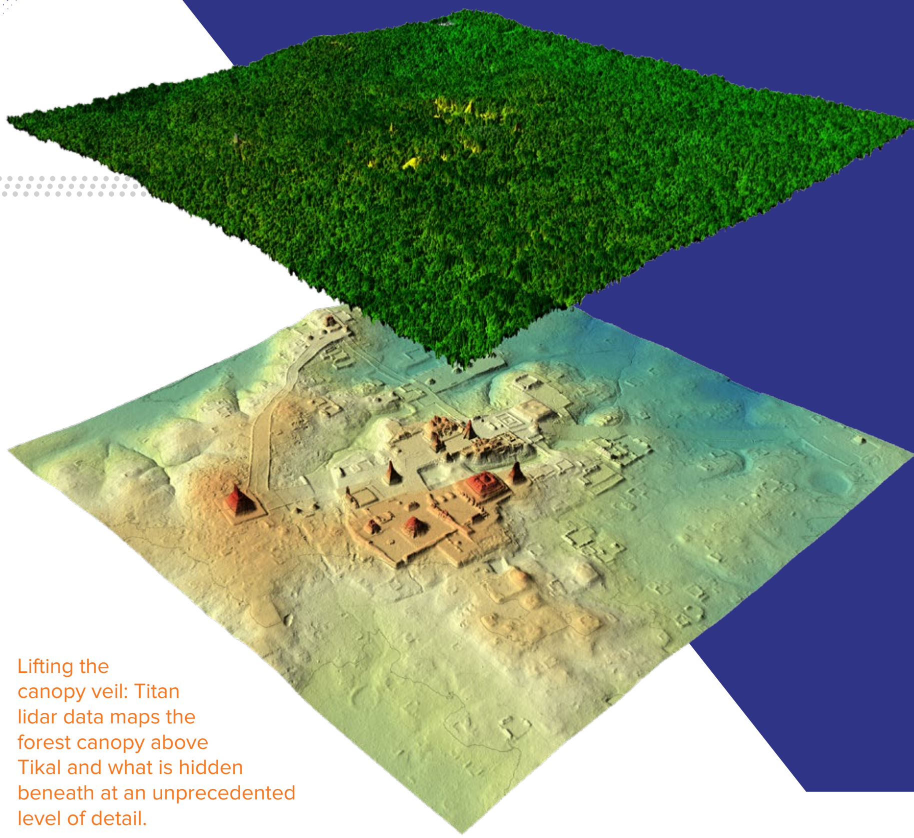


Four lidar data products from the Maya site of Copán in Honduras.

Gathering speed

Still, it would be a few years before lidar would start turning heads in the Mesoamerican archaeological world. The technology and supporting software needed some refinement, and this came only came when the National Center for Airborne Laser Mapping (NCALM), which at the time was partially based at the University of Florida, made a survey in Belize. Unlike the survey of Copan, this one was intended to be an archaeological survey from the start. Moreover, NCALM was equipped with an Optech ALTM Gemini, which contained several years of upgrades over the ALTM 1225.

For example, the ALTM Gemini could fire more laser pulses per second (defined as its pulse repetition frequency or PRF), which greatly increases the chances of having laser pulses find holes in the thick rainforest. In all forests, a certain percentage of laser shots will be completely blocked by the foliage so that none of the laser energy reaches the ground and returns to the sensor at all. While temperate forests in places like California block 70-80% of laser shots, the thick rainforests in the tropics can



Lifting the canopy veil: Titan lidar data maps the forest canopy above Tikal and what is hidden beneath at an unprecedented level of detail.

often block up to 96% of them, leaving only a tiny fraction to hit the ground.

The ALTM 1225 had a PRF of 25 kHz so it fired about 25,000 shots per second, of which only a thousand or so actually reached the ground. That may sound like a lot, but it actually makes for very sparse data when the aircraft is moving quickly. An analyst may be able to pick out large features such as a grand temple or palace in such low-resolution datasets, but could easily miss smaller yet still significant features. By comparison, the Gemini's maximum PRF was 166 kHz, six times faster than the ALTM 1225, so it could put several thousand points on the ground per second. This greatly improved the resolution and fidelity of the final maps, making it much easier to see the remains of small buildings.

Another crucial upgrade was the pulse width of the laser pulse, essentially a measure of how long the laser is firing each pulse. The longer the pulse width, the more difficult it is to distinguish between separate objects in the same pulse. For example, a lidar with a long pulse width might not be able to tell apart the return from a bush and the return from the ground beneath it, leading to an inaccurate measurement of the ground's elevation. The older ALTM 1225 had a long pulse width that could only distinguish objects that were 5 meters apart, but the Gemini's shorter pulse width let it distinguish objects that were 2–3 meters apart. This was very useful for surveying in parts of the rainforest with heavy undergrowth (which was pretty much all of it).

Searching for a lost city

NCALM's excellent results with the survey of Caracol in Belize using the Gemini caught the eyes of many people involved in researching the ancient cultures of the Americas, which led to considerably more work in Belize and Mexico. One of the people interested in lidar was filmmaker and adventurer Steve Elkins, who had spent years trying to locate traces of a legendary "lost city" in north-eastern Honduras.

His proposal to NCALM was an interesting one: instead of surveying around pre-discovered ruins, could the Gemini search a wide area for ruins that researchers weren't even sure existed? The land here is so remote and uninhabited that the rivers and mountains don't even have names in the official maps. Such a shot in the dark would be almost impossible on foot (indeed, Elkins had tried to find the city for years that way). Intrigued and inspired by the challenge, NCALM, whose operational arm had recently moved to the University of Houston, took on the project.

Identifying a "lost city" within a large geographic area is a multivariable optimization problem that depends on the altitude, speed, and PRF of the lidar. On the one hand, the searchers wanted to cover the largest possible area in the least amount of time and cost, which required flying at a higher altitude with a faster airspeed and a higher PRF. However, their ability to obtain ground returns through the thick tropical canopies depended on two factors: a) being lucky enough to illuminate gaps in the canopy through which the laser energy can pass, and b) ensuring that the laser shots that go through the gap have sufficient optical energy that enough of their photons can make the return trip to the sensor and be recorded by the detector.

To increase the chances of putting laser pulses through gaps in the canopy, the searchers must increase the laser sampling, which means illuminating as much surface area as possible with laser footprints. They can accomplish this by flying higher (which increases the footprint size) and employing a higher PRF (which decreases the space between the

2016 excavation of stone artifacts found at one of the many lidar-identified sites in the Honduran Mosquitia.

footprints). Unfortunately, flying higher weakens the returning optical signal, making it harder to detect. Moreover, with the laser technology at the time, increasing the PRF would also reduce the energy packed in each laser pulse.

NCALM's Gemini was at the time the best tool to overcome these challenges. Firstly, the Gemini was designed with a dual divergence mode, which enabled the operator to adjust the laser footprint size between two settings: Narrow and Wide. From a flying height of 1000 m, the footprint had a diameter of 25 cm in Narrow mode or 80 cm in Wide mode. Narrow mode allowed for a more precise height measurement at a lower surface illumination fraction, while Wide mode increased the surface illumination area for each footprint by a factor of 10, albeit at lower precision. Normally, Wide mode would also result in a weaker signal and lower power density. However, NCALM had had its Gemini customized years earlier to counteract this effect by boosting the laser power when it was in Wide mode. This allowed NCALM to achieve both a strong signal and large laser footprints, which was ideal for finding gaps in the dense tropical forest canopies.

After flying the same experimental test line at 600 m above the jungle's canopy top repeatedly with varying PRF and divergence settings, NCALM determined that the Gemini detected and recorded the most ground returns when it was operated at 125 kHz with Wide divergence. This combination was the "sweet spot" between surface illumination and laser pulse energy, and NCALM used it to perform the entire survey.

These technologies made the survey in Honduras quite successful, covering 140 square kilometers in only eight flights and revealing several small settlements composed of structures and plazas scattered here and there. Although this was not enough to count as an entire "lost city", it was a larger habitation area than had been documented before in the neighbouring regions. Even to this day, very little is known about the people who inhabited this part of Honduras, so a team of archaeologists and a production crew from National Geographic set foot in the jungle to verify the apparent archaeological sites. On-site, they confirmed that the structures in the lidar data were indeed created by humans and discovered a large collection of carved stone objects which included metates (grinding stones) and vessels that were apparently left behind as offerings when the residents abandoned the sites.

Sensor window of the Optech Titan multispectral lidar.

Significant as this survey was, it was the next collaboration between NCALM and National Geographic that would create the biggest waves so far in both the media and the scientific community, and also showcase the abilities of the very latest lidar technology.

Seeing in color

NCALM's results had with the Gemini, along with its first survey using a new sensor in Guatemala in 2015, impressed the Pacunam Lidar Initiative, a joint effort of researchers from Guatemala and international institutions led by the Fundación Patrimonio Cultural y Natural Maya. Pacunam tasked NCALM with surveying a large portion of the Maya Biosphere Reserve in the northern region of Guatemala known as Petén, including the famous Maya city of Tikal. This area was truly gigantic, consisting of ten separate areas totalling 2100 km^2, 15 times larger than the survey in Honduras.

By now, NCALM had a new lidar tool to tackle this challenge, the ALTM Titan. Teledyne Optech originally designed this next-generation lidar for NCALM to create high-density maps of land and shallow waters simultaneously, but its unique design made it shine in many other applications as well, including archaeology.

Oblique aerial photo of the Grand Plaza in the Maya city of Tikal in Guatemala.

First of all, the Titan uses a total of three separate laser channels, each firing at up to 300 kHz. This lets it fire 900,000 times per second, over 5 times faster than the single-laser Gemini. In addition, each laser is set at different angle, with one pointing straight down, one pointing 3.5° forward, and one pointing 7° forward. These different angles improve the chances that part of a laser beam will slip through gaps in the foliage and reach the ground, resulting in fewer wasted canopy-only shots. Finally, the Titan's pulse width is even shorter than the Gemini's, letting it get valid ground returns from under vegetation as low as 1.5 meters.

The result of all this was high-resolution, high-fidelity maps that revealed over 60,000 human-made and human-modified structures, many of which were previously unknown to modern science. Some researchers estimate that this survey enabled the identification of about 80% of all the structures that have enough surface relief that they could possibly be found under the forest using lidar. Archaeologists can also now see subtle features such as canals, building foundations, small houses, and raised agricultural fields carved out of swampy areas, greatly improving their knowledge of the population that lived in the area.

Laser design itself has also improved, with considerable benefits to the Titan's efficiency. Because the Gemini's laser tended to lose power when it was operating at its highest PRF, NCALM rarely used it at this setting for terrain mapping in dense jungle environments. To combat this effect, the Titan uses new lasers that do not suffer this drop-off, so it can use its maximum PRF without compromising the detection of faint ground returns. This enabled NCALM to cover 2100 km^2 in the Maya Biosphere Reserve at 15 laser shots/m^2 with just eight flights.

The Titan's most innovative feature, however, is that it can essentially see the ground in "color". Most lidar systems use a single laser operating at a single wavelength, but each of the Titan's three laser channels operates at a different wavelength: 532 nm, 1064 nm, and 1550 nm. This feature was primarily intended to help the Titan in its role as a topographic/bathymetric survey system (the 532-nm channel excels at surveying through water, while the others work best in surveys over land), but NCALM found an entirely different use for it.

All materials reflect light differently at different wavelengths, and that includes the three wavelengths used by the Titan. In other projects conducted by NCALM, false-color intensity maps have revealed the remains of ancient agricultural wetland fields where the topographic models just show flat terrain. This is possible because soils that had been irrigated in ancient time for agriculture still have different moisture levels from unirrigated land, and therefore show different responses at each wavelength.

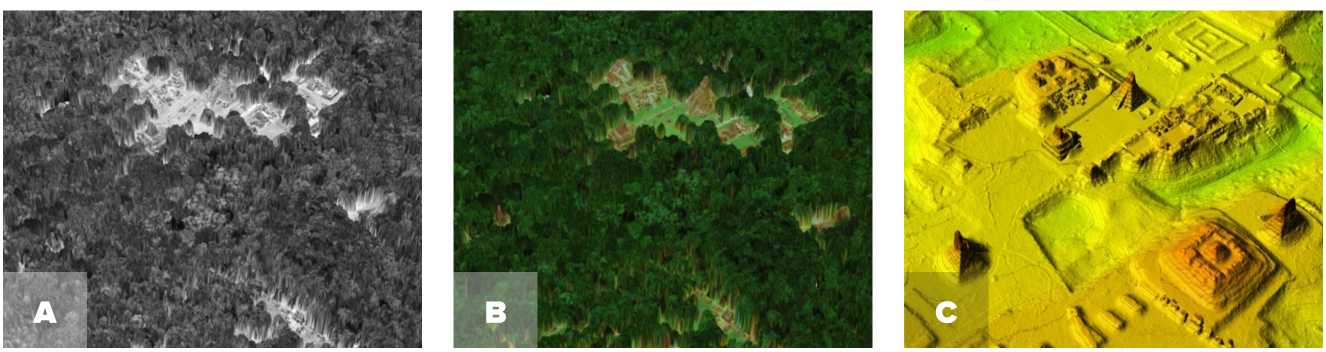
Preserve and protect

These technical advances make airborne lidar systems an important tool for the identification and mapping of archaeological sites hidden beneath rainforests. Breakthroughs in archeological science have been the results of advances in lidar technology. While NCALM's current schedule includes more surveys in Mexico, Guatemala, and Central America, the next big frontier is expected to be the Amazon. Large parts of this enormous rainforest remain uncharted, but modern airborne lidar systems such as the Titan are clearly the best tools to map it quickly and efficiently.

This is fortunate, because time is running out for these sites. Looking back at the areas surveyed in Honduras during the first airborne lidar survey in 2000, many sites have been overrun by new urban areas, cleared for cattle grazing, or turned into plantations of palm trees. As human populations expand, archaeologists and activists will have their hands full working to prevent further destruction of Central and South America's cultural heritage, a task that should be made easier with a catalogue of sites made possible through airborne lidar and other technologies. In the end, these systems won't just help find these sites, but also protect them.

Andrew Moller is a Technical Writer at Teledyne Optech, and has a degree in Classical Studies from the University of Waterloo.

Dr. Juan Carlos Fernandez-Diaz has been with The National Center for Airborne Laser Mapping (NCALM) since 2005 and has coordinated 18 archaeological lidar surveys totaling over 5600 km^2.



The core of Tikal seen in Optech Titan multispectral lidar data: A) First-surface DSM colored with 1064-nm lidar intensities; B) First-surface DSM colored with multispectral intensities (R: 1550 nm, G: 1064 nm, B 532 nm); C) Bare-earth DEM colored by elevation.

3D Mapping on the Move: Making Fantasy a Reality

Kaarta Mobile Mapping Revolutionizes Laser Scanning

Figure 1: Kaarta Stencil 2 modular and customizable 3D mapping and real-time position estimation system.

The Tricorder from Star Trek and the "pups" from Prometheus are Hollywood's idea of a futuristic means to sense and capture surroundings instantly—almost magically—wowing onlookers with three-dimensional representations right before their eyes. Now Kaarta[1], a pioneering Pittsburgh-based startup, has brought this science-fiction fantasy to life by deploying its robotics-based technology across many applications.

1 Further information, including a number of videos, is available at www.kaarta.com.

BY KATHY **PATTISON**

Kaarta captures real-world spaces and instantly produces a high-fidelity 3D map, or "digital twin," of that environment. The company uses mobile lidar (light detection and ranging) scanners, powered by its proprietary software, to reproduce the surroundings digitally, on the go. Spaces can be natural or man-made, and as varied as office buildings, stadiums, warehouses, factories, bridges, ships, power stations, mines, forests, and archeological sites.

Kaarta's breakthrough technology is the purpose-built Kaarta Engine, a novel approach to real-time mapping and localization that intrinsically understands an environment, both capturing what is around it (mapping) and where it is in that environment relative to the map (location). The technology has roots in robotics principles—what Kaarta CEO Kevin Dowling (**Figure 2**) calls "adding robot smarts to 3D modeling."

What brings this core technology to life is Kaarta's range of scanning systems, equipped with an array of lidar, motion, and camera sensors that sense, scan, process, and digitally reproduce the surrounding conditions—all on the go without the need for external signals such as GNSS or prior maps.

Unlike Hollywood fictional tech fantasies, Kaarta solutions are real. They're in use today across a range of applications in the built world, spanning architecture, engineering, construction & operations (A/E/C/O), industrial and infrastructure planning, and even in helping autonomous mobile robots intelligently navigate their workspaces.

Figure 2: Kevin Dowling, CEO, Kaarta, Inc.

> "The algorithms that make up Kaarta Engine are inside our systems, and that is where the magic happens. We have artfully solved the SLAM problem without using traditional SLAM techniques."

Beginnings

So how did Kaarta begin? "It's a fun story," says Dowling, who holds a master's degree and a Ph.D. in robotics from Carnegie Mellon University (CMU) and was part of the formation of CMU's famed Robotics Institute and Field Robotics Center. "When I was a student back in the 1980s, a robotics problem was posed: it's called SLAM, simultaneous localization and mapping. It is where you construct a map of an unknown environment while at the same time keeping track of an agent's location within it."

SLAM is a conundrum, and as such, it's hard to solve. Still, a solution must be found for a robot to operate. People have worked on solutions to SLAM since the 80s, but Dowling didn't see an effective approach until three decades later when he met up with an old colleague, Sanjiv Singh, and his graduate student, Ji Zhang, at Carnegie Mellon's Robotics Institute. Zhang was developing a radically different approach to the SLAM problem. Dowling was astounded by Zhang's ingenuity and could see how his work had far-reaching implications beyond autonomous robotics applications, the primary driver behind most SLAM research.

In 2015, Zhang and Singh founded a company to apply the technology to 3D modeling applications. Months later, Dowling joined as CEO to turn the company's research into a business, commercialize its technology into products, and build out its sales, marketing, and engineering functions.

One of Dowling's first changes was the company's name. "I came up with the name Kaarta to connote cartography, the ancient art and science of mapmaking," he says. The name—with the extra a added for effect—captures the company's pioneering take on mapping to produce 3D models in real time. "The name is not about the technique we use, it's about the problems we solve," says Dowling.

Kaarta started with minimal capital and maximum sweat equity. At the onset, Dowling didn't take a salary. While those initial scrappy times are now behind it, Kaarta still runs a lean operation, maintains its culture of putting innovation first, and keeps an "all hands on deck" attitude for the many tasks at hand.

In operation for three years, Kaarta has made impressive strides in continuous technology and product development, market penetration, and financial performance. Though the company is based in the U.S., more than 60 percent of its business is in Asia, Europe, and the Middle East. "We have taken a global approach to this business from day one and have capitalized on those markets that are early and eager technology adopters," Dowling says.

"Investors," he says, "are pleased with the company's progress and realize its considerable market opportunity." In March 2019, Kaarta raised a Series A round of funding

Figure 3: Kaarta Contour integrated mobile mapping system.

to bring in additional talent and enable an accelerated path to further innovation, partnerships, and growth.

Building the team

Dowling came to Kaarta after 20 years of development and commercialization of industry-first technologies in robotics, semiconductors, LED lighting, wearable electronics, and consumer products. Experience taught him that hiring the right people with the right experience was critical for a nascent company.

He recruited a seasoned leadership team that included two former trusted colleagues: Wade Sheen would head up global sales and business development and Kathy Pattison would lead marketing initiatives. Sheen and Pattison brought plenty of startup experience and a growth mindset. “There are always difficult challenges and obstacles in charting the course of a new business. It’s much better to navigate those waters with a known and proven crew of smart and resilient people,” Dowling says.

Because of the company’s location in Pittsburgh, a hotbed of robotics and AI innovation, Kaarta tapped the CMU brain trust for its engineering talent. Heading Kaarta’s engineering team is Steve Huber, a rocket scientist who has always had a passion for robotics. Steve got his start in robotics in high school through the FIRST Robotics Competition[2] program. Now, Kaarta is a sponsor of a regional FIRST competition, hoping to inspire the next generation of roboticists.

Technology and products

A cursory look might leave the impression that Kaarta is a hardware company, but closer inspection shows it really is a software company that packages technology innovation in a physical system. “The algorithms that make up Kaarta Engine are inside our systems, and that is where the magic happens,” Dowling says. “That is what differentiates us. We have artfully solved the SLAM problem without using traditional SLAM techniques.”[3]

Beyond Kaarta Engine, Kaarta’s software development focuses on the utility, usability, and capabilities of mobile mapping through its on-board software. The software delivers a more efficient workflow through advances such as providing confidence metrics to help users capture a better scan, to delivering new color capabilities, to reducing or eliminating post-scanning processes. The company is leveraging these innovations to build a large, diverse portfolio of patents on its inventions. Its first patent was issued in mid-2018, and many more are in the pipeline.

In 2016 Kaarta introduced Stencil, a modular and customizable 3D mapping and real-time position estimation system delivering capabilities tripod-based scanning systems lack. Stencil scans exterior and large interior spaces without the need for existing infrastructure, external signals, or prior maps. Far more than just a mobile scanner, Stencil processes while capturing, making intelligent decisions to use only good data, and generating a registered point cloud

2 firstinspires.org.

3 Details of Kaarta’s algorithms have been published in academic journals, for example:

Zhang, J. and S. Singh, 2014. LOAM: Lidar Odometry and Mapping in real-time, *Proceedings, Robotics: Science and Systems 2014, Berkeley, CA, USA, July 12-16, 2014: 9 pp.*

Zhang, J. and S. Singh, 2015. Visual-lidar odometry and mapping: low-drift, robust, and fast, Proceedings, *2015 IEEE International Conference on Robotics and Automation (ICRA) Washington State Convention Center Seattle, Washington, May 26-30, 2015:* 2174-2181.

Zhang, J. and S. Singh, 2018. Laser–visual–inertial odometry and mapping with high robustness and low drift, *Journal of Field Robotics,* 35(8): 1242-1264, December.

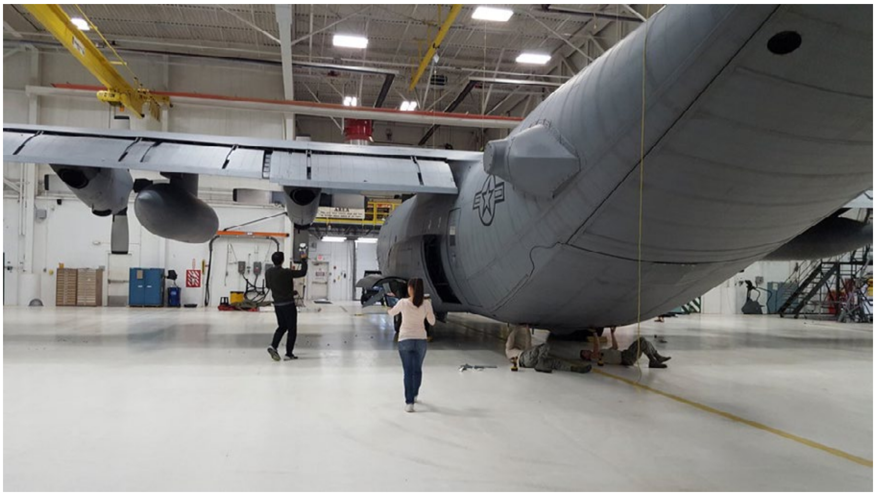


Figure 4: Operator hand carrying Kaarta Stencil to map C-130 Hercules.

on the fly. Early on, Stencil's accuracy was put to the test in the Microsoft Indoor Localization Challenge, where it grabbed first place in 2016 and 2017[4].

The recently launched Stencil 2 (**Figure 1**) improves upon the original system with a new user interface, wireless tablet display, and the addition of GNSS support to correct for drift over large areas.

In 2017 Kaarta launched Contour (**Figure 3**), putting the same fundamental capabilities in a sleek hand-held design ideally suited for interiors and tight, complex spaces. Contour is a totally integrated system with a color camera and its powerful Reality Layer which enables one-click cleanup and colorization. Outputs range from point cloud to surface mesh to rich photorealistic model.

Applications for Kaarta's technology exceed the company's market focus, but Kaarta works with partners to help them integrate the technology in other solutions through development kits and non-recurring engineering support.

Important to the rapid future advancement of its mobile mapping solutions and other applications through OEM or licensing partnerships is that Kaarta's software is relatively hardware-agnostic. This flexibility gives Kaarta the agility to incorporate the latest off-the-shelf components: as better performing and new forms of lidar and other sensors come to market, Kaarta is able to evaluate and incorporate them quickly. Dowling summarizes, "The key aspect of our software is knowing how to integrate it with hardware so that the complete system delivers value to the user. The integration of best-in-class software and algorithms with the enabling hardware is key to Kaarta's success."

In addition to the above activities, Kaarta offers Kaarta Cloud[5], a processing service to generate 3D models of raw Velodyne lidar data. In the near future expect additional services that will let users send captured data directly from a device with one click, store it in the cloud, and within a couple of days turn the captured point clouds into floor plans, CAD, and BIM models.

4 microsoft.com/en-us/research/event/microsoft-indoor-localization-competition-ipsn-2016/#!official-results and microsoft.com/en-us/research/event/microsoft-indoor-localization-competition-ipsn-2017.

5 kaarta.com/instructions.

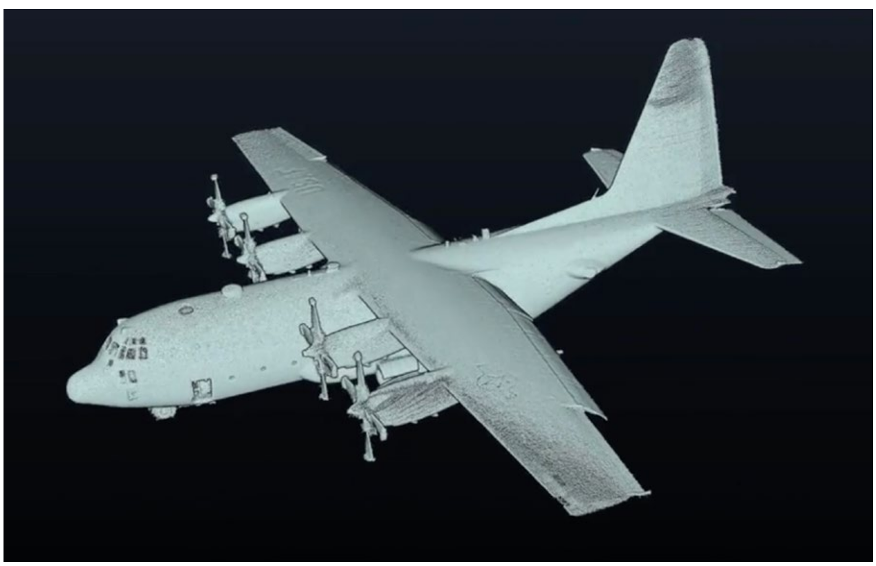


Figure 5: C-130 Hercules point cloud captured and processed with Kaarta Stencil

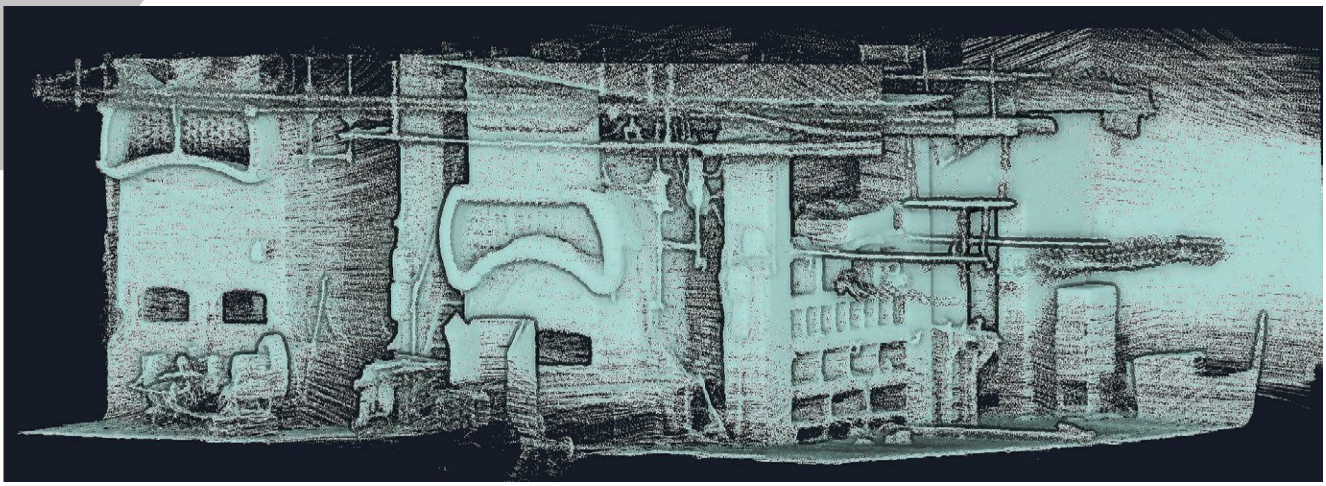


Figure 6: Point cloud of underground boilers exposed following a fire. Captured and processed with Kaarta Contour.

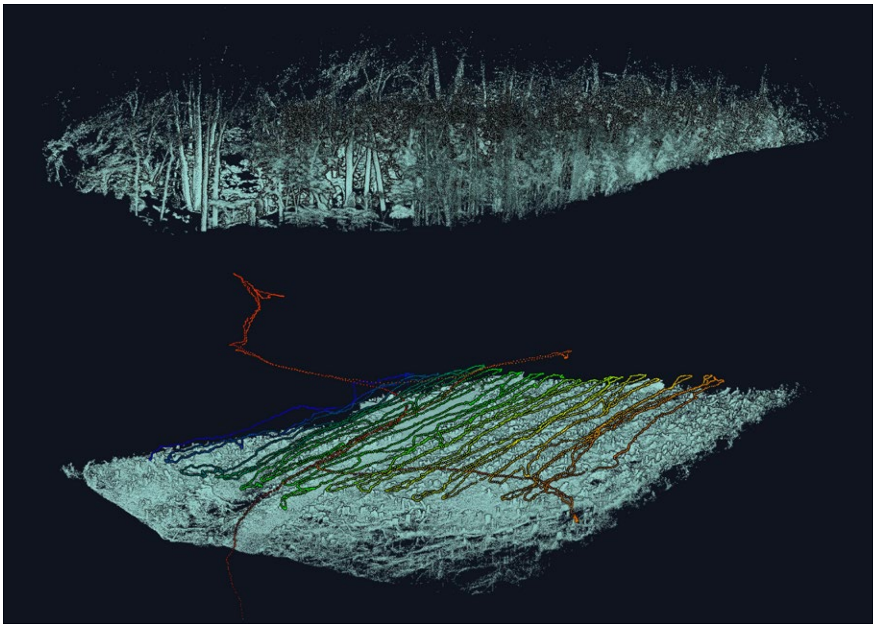


Figure 7: Cut away slices of terrain, scan path and vegetation of dense wooded area scanned and processed with Kaarta Stencil.

Limitless applications

Early on, hungry to prove its technical prowess, Kaarta brainstormed ideas to demonstrate its capabilities. "We wanted to map something more complex than a boxy, flat room," Dowling says. So they went big—indeed, Herculean. They captured a 3D model of the exterior of a massive Lockheed C-130 Hercules military transport aircraft, to model it and determine the feasibility of implementing an autonomous paint-removal system for routine maintenance. Using tripod-mounted terrestrial lidar or drone-mounted lidar to capture the full surface of the aircraft would have been extremely time-consuming and would require many scans. Stationary systems would require many views to capture the complex geometric surfaces of the aircraft, especially near the engines and propellers, all of which would have to be processed and registered in post-processing. With Kaarta, the operator hand carried Stencil, first walking around the aircraft (**Figure 4**) and then using a lift to gain a vantage point to the top of the plane. Kaarta reveals the model through continuous motion so no surface is missed (**Figure 5**). "The area was large, curved, and complex, yet we had a registered point cloud in 30 minutes," Dowling says. "The result is amazing."

"Scanning complex structures meant there was little limit to what Kaarta's technology could do, including a Frank Gehry building and old ruins," Dowling asserts. An unusual project for the City of Pittsburgh again put the technology to the test. City workers discovered immense boilers under a building that burned down. Previously unaware that these boilers existed, the City asked Kaarta to scan the sunken area and pipework to document the site. "We

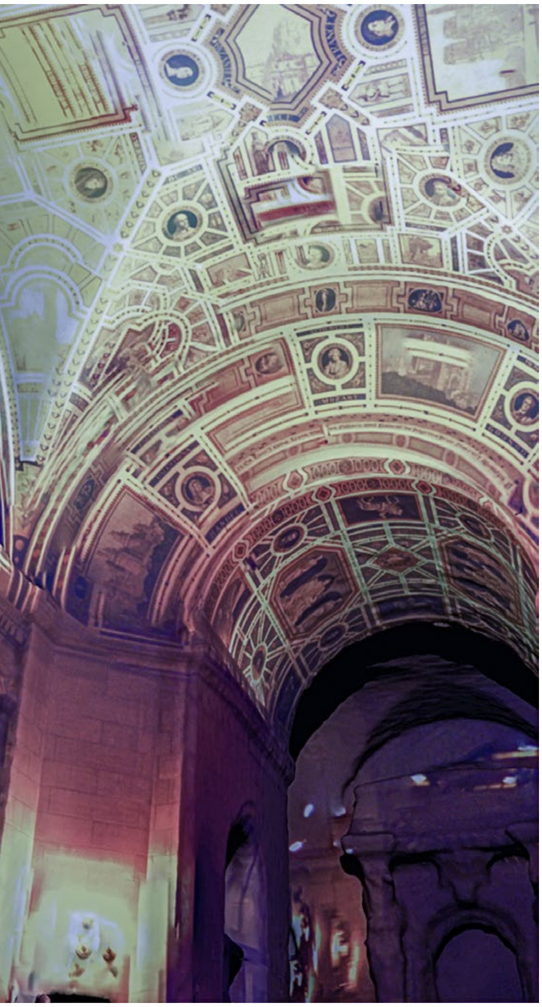


Figure 8: Reality Layer colorized point cloud captured and processed with Kaarta Contour.

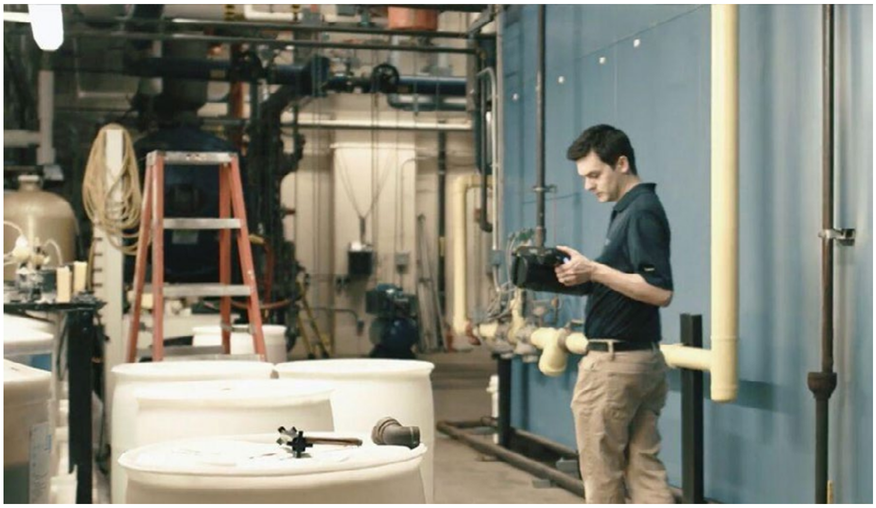


Figure 9: Mobile scanning with Kaarta Contour.

walked through the space and it was dark, ominous, intricate, and detailed," Dowling says. Kaarta technology quickly and easily captured the entire area (**Figure 6**). Matthew Jacob from the City of Pittsburgh Department of Public Works adds, "We really put [Kaarta] technology to the test. We took them all over the city. We took them to rooftops, to abandoned buildings, and we were pretty pleased with the results."

A marine surveyor used Kaarta to scan the existing conditions of an oil tanker that sails the Gulf of Mexico to plan for ballast water treatment retrofits. Rarely in port for more than 48 hours, two decks high, and bearing an intricate maze of complex piping systems, this type of vessel has traditionally been a nightmare to capture. With Kaarta a highly accurate 3D model was quickly built.

On dry land in the woods of rural Maryland, the design, engineering and program management firm CH2M (now part of Jacobs Engineering Group) was testing another application for Kaarta technology. The project would test the rigor of Kaarta's system and explore its use for mapping applications requiring high precision in GNSS-denied environments to integrate with advanced metal detection and classification systems for locating buried ordnance.

The status quo for positioning with these systems is time-consuming and does not provide positioning accurate enough for consistent results. The area's rugged terrain and dense vegetation posed a special challenge but the survey (**Figure 7**) was completed within 30 minutes. All of the previously surveyed points were accurately identified and the difference between Kaarta's rapidly scanned points and those that were meticulously surveyed through conventional means ranged from just 3.5 cm to 19.8 cm. "Precise positioning is fundamental to our work, and to produce these results with such relative ease and cost efficiency is eye opening," says Tamir Klaff, principal technologist at CH2M. "We undertake many projects in environments where this technology will undoubtedly be a key problem solver."

Kaarta set its sights high to test its Reality Layer colorization capabilities by scanning one of Carnegie Mellon's Beaux Arts buildings. The entrance resembles a cathedral with an eclectic ceiling mural depicting images of great works of architecture. Kaarta captured it in all its glory in 20 minutes. The results in full color (**Figure 8**) were impressive and some viewers had to be reminded that it was a point cloud and not a photograph.

For facilities inspection company Fasttac, based in Pittsburgh, Pennsylvania, Kaarta's colorization capabilities served more utilitarian

Figure 10: Colorized point cloud of tight spaces within hospital boiler room captured and processed with Kaarta Contour.

purposes. Fasttac used Kaarta to capture the existing conditions of the boiler rooms of a major medical center (**Figures 9 and 10**). "Kaarta is a huge win for applications such as facilities maintenance, since it is incredibly easy to capture the layout of spaces that do not have up-to-date drawings, and that's about 90% of existing buildings," says Ray Steeb, CEO of Fasttac. "The key is that we can then use the scans right away without having to model." Steeb was particularly impressed with the colorization of Reality Layer, which makes it even easier to identify any given area visually.

In a return to its roots, Kaarta is also seeing many applications for its technology in "mapping for robots"—aiding autonomous mobile robots programmed to do everything from cleaning floors and bathrooms to taking inventory to delivering packages to your front door. Even robots can benefit from the specialty of other robots.

Endnote

And so it comes full circle. Robot smarts perform miracles inside a system that captures the world outside, bridging the physical world with its 3D digital twin. With conceptual origins in solving a robotics problem posed decades ago, Kaarta is well positioned to answer those two fundamental questions of today: "Where am I?" and "What's around me?"

Kathy Pattison is CMO of Kaarta. She has spent the better part of her 30-year career in early- to mid-stage startups that have brought transformative technologies to life, and really wouldn't have had it any other way. Kathy also serves on the board of directors for numerous not-for-profit organizations.

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microsoft.com/en-us/research/event/microsoft-indoor-localization-competition-ipsn-2016/#!official-results

Mixed reality is a form of augmented reality (AR) that merges real and virtual worlds to create brand new environments where physical and digital components interact in real time. With Trimble Connect for HoloLens, users can interact with what they see on a 1:1 scale and compare components against design and installation guidance.

Trends to Watch

Geospatial's Next Wave of Innovation

There's no question digital transformation is making geospatial technology increasingly relevant in industries globally, whether adding precision to a position, context to mass data collection, or content and attributes to a project model.

Spurred by an evolution in computing power and connectivity that soon will improve exponentially with 5G connection speeds, the rise in global demand for geospatial data and geo-enabled devices is propelling technologies to evolve. In fact, according to a recent GeoBuiz report, the global geospatial market is expected to grow an estimated 13.6 percent through 2020, significantly faster than the growth rate of 11.5 percent from 2013-2017. It also shows the GNSS and positioning industry—the largest of the geospatial universe—is

BY BORIS **SKOPLJAK** AND CHRIS **TREVILLIAN**


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With the Trimble MX9 Mobile Mapping System, all sensors are time synchronized with precise GPS time tags and are linked to the trajectory that is recorded with the GNSS/IMU subsystem. That way, all recorded points and images can be properly aligned in a post-processing step.

estimated to grow at a CAGR of 13.5 percent to reach $260.8 billion in 2018-2020. The GIS and spatial analytics market is the second largest, the report states, with rapid growth expected to continue from $66.2 billion (a 2017 estimate) to $88.3 billion in 2020.

Scanning the horizon, these questions emerge: What technologies will transform the geospatial industry in the next few years? What are the next big steps required to make spatial content more relevant?

Geospatial professionals are hungry for advances in technology that can help them do more, including providing richer, more insightful deliverables to general contractors, civil engineering and construction teams, designers, business owners and key project stakeholders.

When considering the next wave of geospatial technology, the most disruptive themes include sensor fusion, autonomous vehicles, mixed reality, big data analytics, the as-a-service business model and 3D modeling/BIM. Many of these innovations will be available not merely through a single tool, but through the integration of multiple technologies.

Here are the key technology trends we believe will drive the geospatial industry forward over the next 18-24 months:

Sensor Fusion

Sensor fusion is one of the leading edges of product development because of the power that comes from combining multiple different sensor types or technologies in ways that maximize their combined strengths while minimizing their combined weaknesses. The fusion of sensor technologies to include more IMUs, GNSS and emerging technologies like Solid State LiDAR and SLAM processing is making it possible to merge multiple disciplines of mass geospatial data capture into one seamless routine.

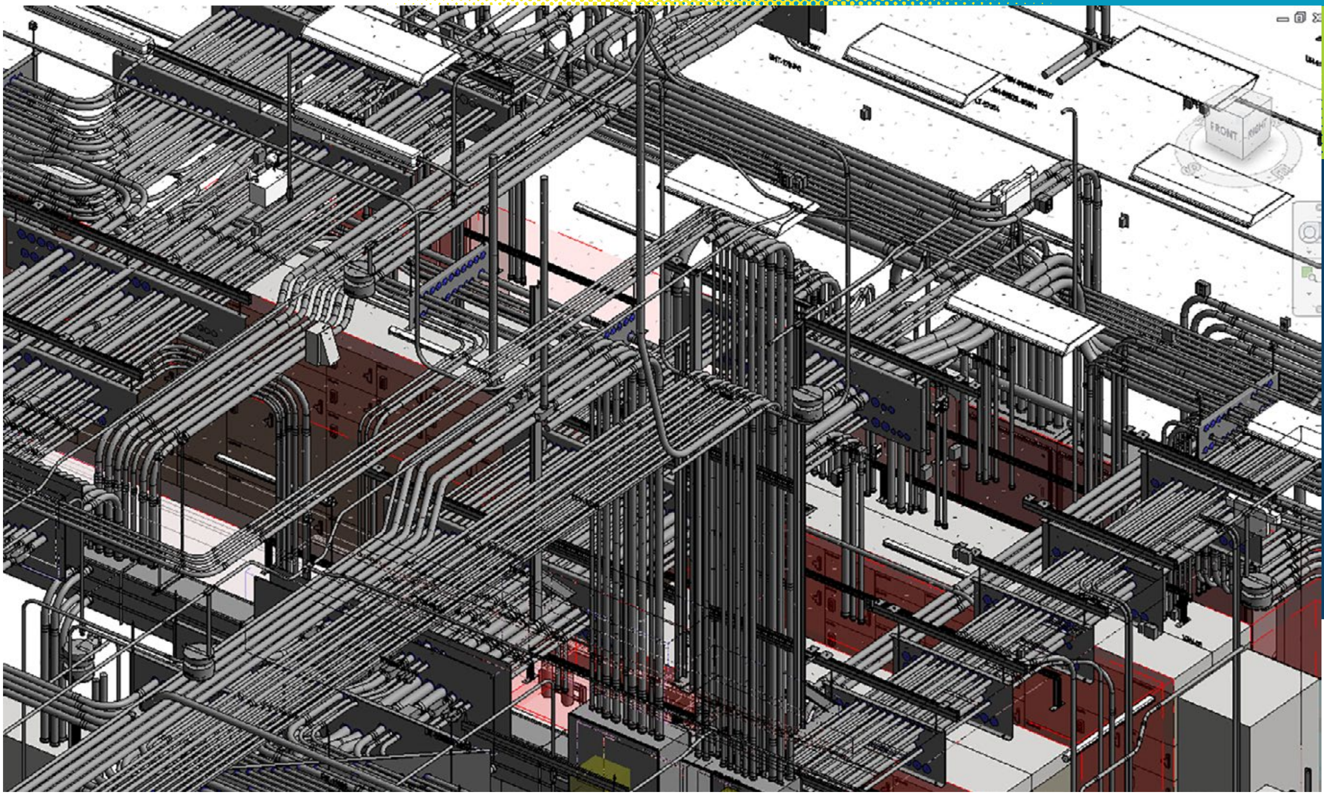
Mobile mapping systems are one example. They combine the various strengths and weaknesses of different types of sensors—inertial (IMU), wheel speed, GNSS, cameras and LiDAR—and fuse these sensor outputs, achieving greater levels of accuracy and detail for engineering operations and design.

Having different types of sensor data can be extremely powerful, but even more beneficial is fusing that data for analysis and decision making. Supported by the right software, sensor fusion is about getting the most out of various sensors and sensor combinations to solve business problems.

This technology integration will remain a growing trend in the surveyor community as more geospatial professionals take advantage of unique sensor combinations purpose-built to help provide better geospatial context.

Data-Driven Decisions

There's been significant effort and accomplishment in making mass data collection easier over the last decade. Looking ahead, geospatial professionals will need to spend an equal amount of effort to make that data useful in



BIM technology creates intelligent models that promote a richer understanding.

meaningful ways. In other words, technology innovators need to provide geospatial professionals with the processing tools and software applications necessary to effectively process the data into deliverables that matter.

Also, because the future geospatial industry has limited tolerance for restraints such as the use of multiple software packages to store and analyze data, we will start to see further adoption of a single geospatial data hub that enables users to bring all disparate data to a single department, enabling field-to-finish with confidence. This central hub will also allow geospatial professionals to choose the best hardware tool for the job, whether they walk it, fly it or drive it to gather data.

The ultimate goal will be to move away from heterogeneous files—and those collections of data—into reusable, more reliable systems of record that can be used across multiple disciplines and multiple user personas. The cloud-based platforms and feature services will play a major role in eliminating unnecessary physical data transfer and connect and enable easier project collaboration and information exchange.

As a Service Business Model

Geospatial customers increasingly see solutions offered as a subscription or pay-as-you go service, rather than a one time purchase. This model is providing benefits to enterprise and large organizations enabling them with a more predictive cash flow. The as-a-service model provides easier access to professional grade measurement technologies, enabling more people to enhance and streamline workflows and project deliverable creation. The as-a-service approach results in more people using their smartphones and mobile devices to receive satellite data for a precise position. This technology advancement will multiply the capability of field organizations to increase the reach and rapidness of data collection in the coming years.

Modeling and Visualization

Geospatial data—such as point clouds, complex meshes and terrain models—are often difficult to explain and deliver to clients. The use of augmented reality (AR) and mixed reality (MR) tools will increase in the next several years to improve understanding of existing site conditions by overlaying models over the existing environment. For example, a user of augmented reality technology could view existing underground services and future landscapes overlaid on a worksite to avoid hitting a utility line during excavation work. Other benefits include collaboration, planning and asset management. Organizations that can offer this functionality to their customers will have an edge on the competition.

3D Modeling, BIM

The design and construction industry is at a tipping point in which BIM (Building Information Modeling) can positively impact geospatial professionals' work the more they embrace it. However, prospective BIM adopters need to realize the technology not only provides intelligent 3D modeling, but it also offers a centralized platform for sharing data to help partners communicate effectively – in real-time. When surveyors take advantage of BIM holistically, they are not only factoring in the traditional aspects of a building's design but also generating rich data spanning the range of properties of a structure's components, construction and maintenance.

The challenge with BIM adoption is not just to encourage surveyors to use newer technologies, but rather to convince them to start seeing it as a paradigm shift in the design and build process altogether. At its core, BIM is meant to transform how project teams work together on a job, from start to finish.

Future Technology Integration: Closing the Gap on Segmented Functionalities

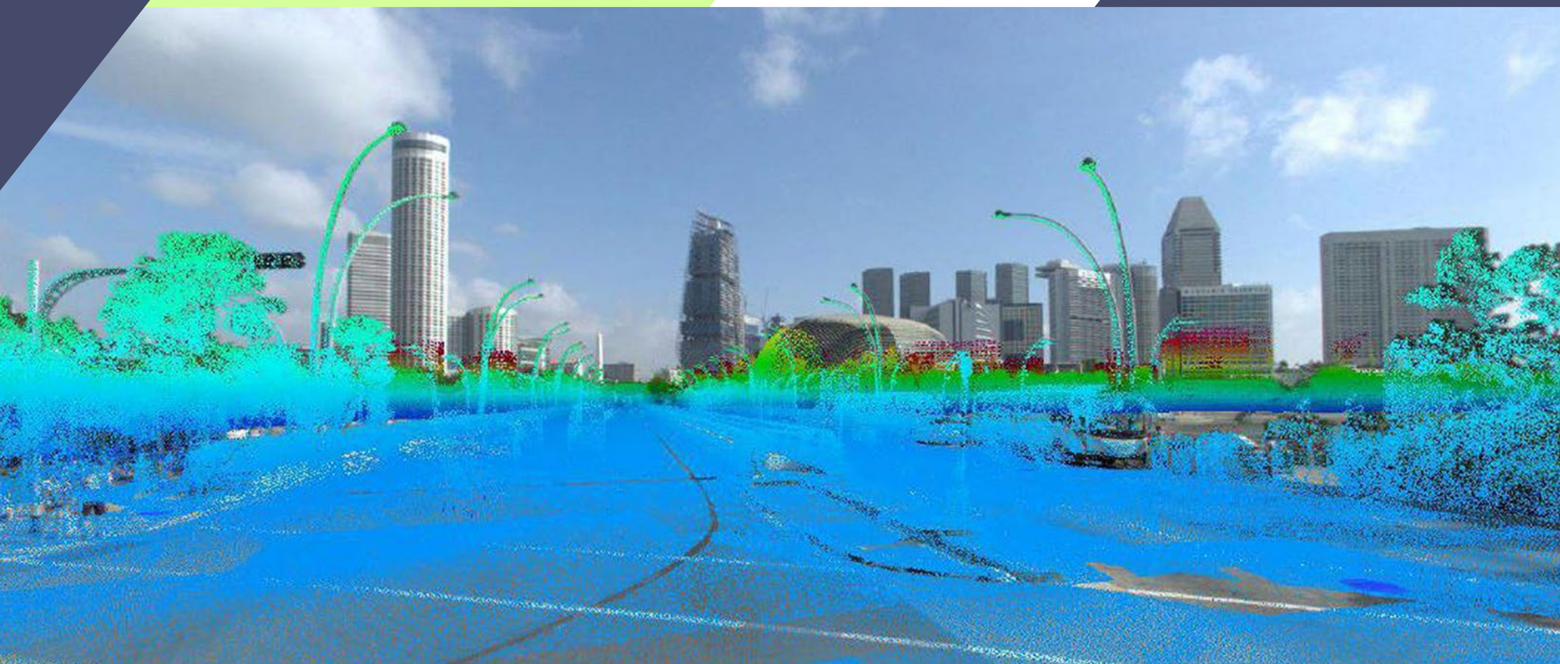
As the digital world continues to evolve, the relevance of geospatial information and technology will continue to build on its current momentum, adding spatial dimensions to many business processes.

Traditional silos that previously segmented functionalities will increasingly dissolve, with further integration driven by cutting-edge technologies. This integration will help reduce the gap between data capture, processing, analysis and delivery of an easy-to-understand, cohesive image of the real world, from surveyor to customer.

Looking ahead, as more geospatial professionals embrace the power of these digital advances, there will be productivity improvements, cost savings and new business opportunities to realize for years to come.

Boris Skopljak is marketing director for Trimble Geospatial strategy and analytics.

Chris Trevillian currently works as market manager within Trimble Geospatial for optical, imaging and 3D scanning solutions.



A Singapore skyline in spherical view with point-cloud overlay

Singapore Smart Nation Embraces 3D Land Management

Orbit GT tools simplify management and use of mobile mapping data

BY JOHNSON **ANG**

As part of Singapore's quest to be a smart nation, the Singapore Land Authority embarked on a 3D national mapping initiative in 2014, involving mapping the island nation via airborne laser scanning, along with airborne imaging, and mobile laser scanning and imaging. Orbit GT technology was used to manage the contents of the downstream mobile laser scanned and imaged data. The ease of use and the interaction of these high-quality datasets with Orbit GT tools have opened up many possibilities for stakeholders within the governmental agencies to manage features and assets of interest efficiently.

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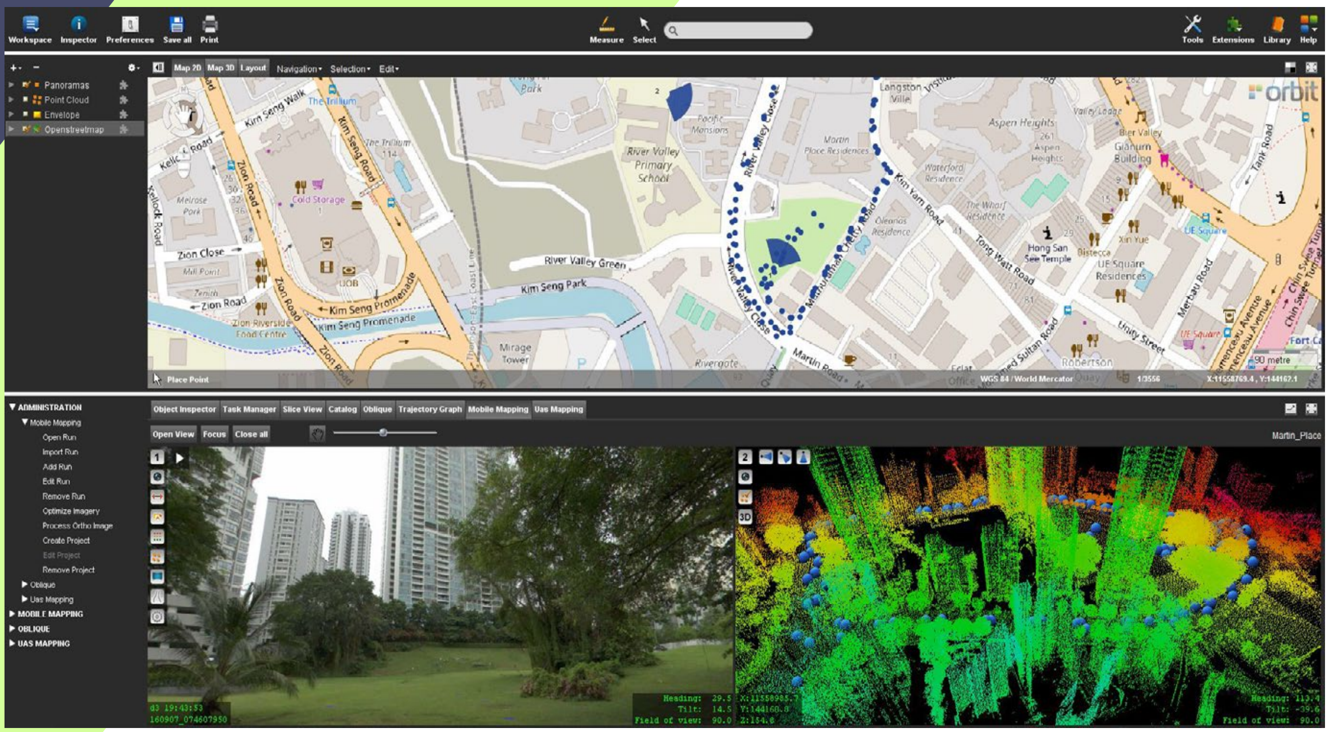


Orbit GT 3DM Content Manager

Introduction

The Singapore Land Authority (SLA) is a statutory board, formed in June 2001 to manage Singapore's land resources. Its vision is, "Managing the country's limited land to create unlimited space". SLA is thus dedicated to optimizing land resources for the economic and social development of Singapore. As Singapore is a small island nation, land needs to be managed in the most efficient way. This can be achieved by creating space above and below ground.

When these spaces are created, 2D maps are no longer adequate to fully represent the real-world GIS information in Singapore. The airspace and subterranean spaces all overlap with the ground level information, making it hard to visualize and represent them on a map.

In 2014, SLA embarked on a journey to create a Singapore Advanced Map by mapping the whole of Singapore with 3D geospatial data through the 3D National Mapping project. This is part of the Smart Nation initiative led by the nation's Smart Nation and Digital Government Office. Its aim is, "Improving the lives of citizens, creating more opportunities and building stronger communities by harnessing technology and gathering insights from data to the fullest."

3D National Mapping

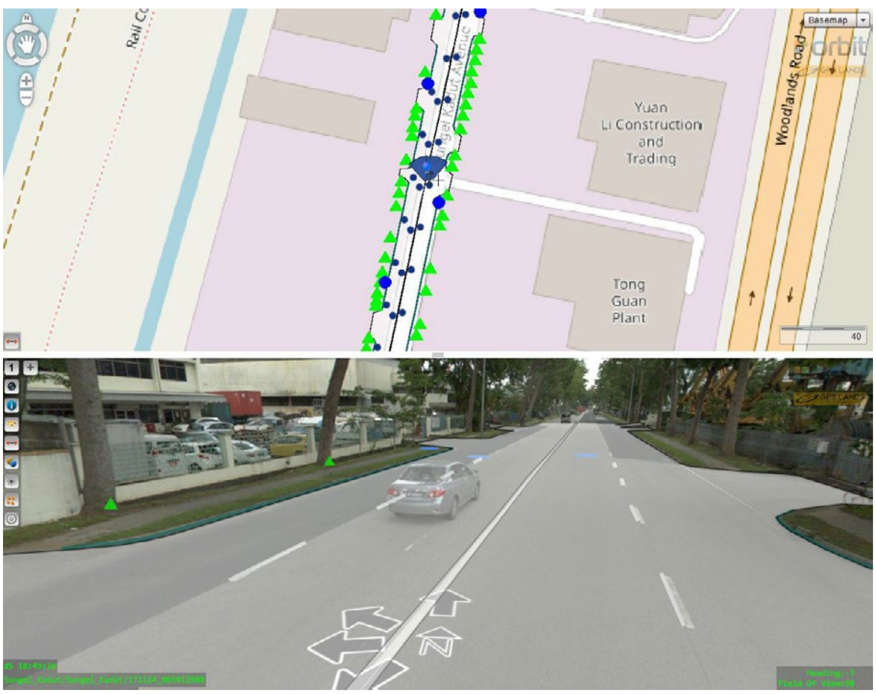
The demand for 3D map data is increasing, as 3D data can assist in land development planning, management of underground utilities and infrastructure, flood management, urban airflow analysis, studies of solar potential, and many other applications.

Factors to consider when defining the methodology to collect 3D data include accuracy, level of detail, reliability, area coverage, data format and appearance. In the traditional approach to collecting GIS data, it is possible simply to perform a 3D topology around Singapore, but the level of detail and appearance will not be adequate for the creation of 3D models: the physical appearance will not match the real-world appearance. Through the use and exploration of advanced mapping technologies, it has become clear that 3D laser scanning with imagery is the best available solution to address the considerations for collecting 3D data.

The 3D National Mapping initiative aims to create and maintain an accurate 3D map that is developed once and used by many. The main objectives are to have: high-resolution data in order to meet the requirements of most government agencies; an open standard data exchange format for interoperability and data sharing; a common, authoritative 3D base map to support collaboration among agencies; and a workflow for continuous maintenance to ensure currency of data.

The 3D National Mapping project is carried out in two phases. Phase one is to capture and create an orthophoto map of Singapore and to capture the digital surface and digital terrain data of Singapore. To achieve the goal for phase one, airborne laser scanning and imagery equipment was used. Two twin-engine aircraft were mobilized, each with a sensor system. The aircraft were pre-programmed with flight path data and flew missions to capture both vertical and oblique images. They simultaneously performed 3D laser scanning. The whole data collection exercise was completed in 40 days. Collected 3D data was then processed and put to use to create the Digital Surface Model (DSM) and Digital Terrain Model (DTM). The images were also used to create an orthophoto of the whole of Singapore. The vertical and oblique images paired with the point-cloud data were used to create 3D building models. This data also serves as a base to create the overall framework of the Singapore Advanced Map.

The second phase of the 3D National Mapping project involved a comprehensive mobile collection of road and street data as furniture to supplement the data collected in the first phase of the project. This was carried out by a mobile mapping laser scanner with a panoramic camera mounted on a vehicle. Ground-based laser scanning and a 360° panoramic imagery dataset were collected on approximately 6000 km of roads in Singapore. This exercise captured all road and street features. This mobile mapping 3D data enriches the airborne 3D data with fine detail, at the same time verifying the accuracy of all the building models.



Overlay extracted objects on spherical view and reference map

Orbit GT Smart City solutions

When the data sets are collected and processed, the question arises how to combine them to verify and view them together. The data sets are huge and the available point-cloud processing software could not handle them. They become useable only when they are pieced together and features can be extracted from the data.

GPS Lands (Singapore), an Orbit GT partner, approached SLA with a solution that allows SLA to piece all verify the data that was collected and processed.

Orbit GT's 3DM Content Manager was used to verify the data that was collected and processed. This software allows the processed point-cloud data and panoramic images to be imported as runs. All the imported runs can be loaded together for viewing as a whole. This is where the data sets can be verified at a large overall scale to check for any mismatched data. The point-cloud data also shows the accuracy of the orthophoto map created from the airborne imagery when overlaid as the base map in 3DM Content Manager.

The features available within the 3DM Content Manager enable SLA to manage the data sets by grouping the data and loading them separately when required. For example, the mobile mapping data of northern Singapore is made up of several point-cloud data sets. In 3DM Content Manager, these data sets can be imported as runs and added into a project to be grouped together. In this way, data can be managed easily, and according to the user's requirements.

A critical component of the 3D National Mapping initiative is data sharing with stakeholders. The main stakeholders come from across governmental agencies, research institutes and other parties of interest. The next step is to be able to extract the 3D features from the GIS data. Orbit GT's 3DM Feature Extraction is the tool to be used by SLA to perform feature extraction from their 3D data. In land management and administration, the exact details on the ground provide crucial information for the government to plan and make decisions. Being able to view rich data captured in 3D without having to be physically on the ground is an efficient allocation of resources.

In a particular example of collaboration with government agencies, tree features across Singapore are being extracted as points, with the attributes of coordinates and height. This information allows relevant agencies to manage the greenery of Singapore, to provide high-resolution information for carbon accounting and also to identify the location and estimate the number of trees on State Land.

There are also other use cases where features such as lampposts, curb lines and manholes are extracted to perform verification of the existing GIS data of other agencies, as part of their asset inventory management. Exact coordinates of the data and accurate measurement can be done without having to go into the field for GIS data collection.

Identifying the features on the ground, then extracting and exporting them allows them to be seen on a map at a single glance. This information can be exported and shared with different government agencies, using GIS data to provide them with visualization of their assets. The extracted features can also be overlaid in 2D form, since the data can be exported in various available formats that can be used immediately with 2D GIS data.

Moving forward

In Singapore's quest to become a smart nation, SLA continues to explore advanced GIS technologies to build and enhance the Singapore Advanced Map. As a plan to move forward on sharing data with various government agencies, SLA is deploying the Orbit GT 3D Mapping Cloud solution for publishing the 3D data. This enables agencies to benefit from the 3D GIS data for their own use cases. ℹ

Johnson Ang is project manager at GPS Lands (Singapore). Originally from the IT industry, Mr. Johnson has 10 years of experience in the land survey industry. His subsequent experience with GPS Lands has allowed him to integrate experience from the land survey industry with IT knowledge, and implement advanced GIS solutions. His team specializes in setup and customization of GPS infrastructure systems and Orbit GT solutions.

Cepton releases *Vista-Edge* LiDAR evaluation and AI software device.

Vista-Edge™ provides customers with cost-effective solution for viewing LiDAR data.

San Jose, Calif.—Cepton Technologies, Inc., a provider of 3D LiDAR solutions for automotive, IOT, industrial, security, retail and mapping applications, today announced the *Vista-Edge™ LiDAR Evaluation Kit,* an edge processing system combining Cepton's Vistaä LiDAR sensor and Nvidia's Jetson TX2 based micro-computer.

The *Vista-Edge™* is a true plug and play device, with all necessary software and tools pre-installed to view and analyze the LiDAR's 3D point cloud of data. The pre-installed software SDK and sample code will accelerate the ability for customers to develop their own product specific software that utilizes Cepton's sensors. Customers who buy the LiDAR Evaluation Kit will automatically be eligible to upgrade to the Perception Evaluation Kit when it becomes available later in 2019.

"Cepton wants to make it easy for our customers to evaluate and test our sensors particularly when rapid prototyping and running Proof Of Concept projects. Customers can now experience the density and range of our LiDAR sensor point cloud without the need to install software, read manuals, buy cables, acquire dedicated processing hardware." said Jun Pei, CEO and co-founder of Cepton Technologies. "Our high resolution, long range portfolio of sensors provide our customers with the richest point cloud data available on the market and *Vista-Edge™* will enable them to better harness and utilize the data, and for us to demonstrate it."

The *Vista-Edge™* features compact, lightweight design and has ports for 1Gb Ethernet, HDMI, USB 3.0 and USB 2.0 connections, and can function on IoT and Wi-Fi networks. Out of the box, the system takes only a few minutes to setup before customers are able to view the LiDAR's data.

"LiDAR-based object detection and tracking can augment traditional computer vision-based solutions," said Murali Gopalakrishna, head of product management, autonomous machines at NVIDIA.

"Cepton's offering delivers rich 3D data, making it easy for our customers to fuse the power of NVIDIA AI with the sensing capabilities of the Cepton LiDAR."

Cepton recently launched two new LiDAR products, Vista-M and Vista-X, designed for all levels of autonomous application, and will begin mass producing its portfolio of LiDAR sensors in partnership with Celestica this year with full volume production by 2020.

Cepton Technologies, Inc. is a 3D sensing solutions provider shipping next-generation LiDAR products for the automotive, industrial and mapping markets. Founded in 2016 and led by LiDAR and advanced image industry veterans, Cepton has a leadership team that recognizes where the automotive industry and Internet of Things (IoT) market are headed and have deployed four advanced LiDAR solutions that are mapping the future. Cepton LiDAR technology delivers unrivaled detection range and resolution at low cost, to enable perception for the fast-growing market for smart machines. For more information, visit cepton.com.

DARPA has issued a Request for Information (RFI) to augment its understanding of state-of-the-art technologies for 3D mapping and surveying.

DARPA Seeks Tools to Capture Underground Worlds in 3D

Request for Information pursues state-of-the-art technologies for collecting and characterizing 3D mapping and surveying data

DARPA is seeking information on state-of-the-art technologies and methodologies for advanced mapping and surveying in support of the agency's Subterranean (SubT) Challenge. Georeferenced data—geographic coordinates tied to a map or image—could significantly improve the speed and accuracy of warfighters in time-sensitive active combat operations and disaster-related missions in the subterranean domain. Today, the majority of the underground environments are uncharted or inadequately mapped, including human-made tunnels, underground infrastructure, and natural cave networks.

Through the Request for Information, DARPA is looking for innovative technologies to collect highly accurate and reproducible ground-truth data for subterranean environments, which would potentially disrupt and positively leverage the subterranean domain without prohibitive cost and with less risk to human lives. These innovative technologies will allow for exploring and exploiting these dark and dirty environments that are too dangerous to deploy humans.

"What makes subterranean areas challenging for precision mapping and surveying—such as lack of GPS, constrained passages, dark or dust-filled air—is similar to what inhibits safe and speedy underground operations for our warfighters," said Timothy Chung, program manager in DARPA's Tactical Technology Office (TTO). "Building an accurate three-dimensional picture is a key enabler to rapidly and remotely exploring and searching subterranean spaces."

DARPA is looking for commercial products, software, and services available to enable high-fidelity, 3D mapping and surveying of underground environments. Of interest are available technologies that offer high accuracy and high resolution, with the ability to provide precise and reproducible survey points without reliance on substantial infrastructure (e.g., access to global fixes underground). Additionally, relevant software should also allow for generated data products to be easily manipulated, annotated, and rendered into 3D mesh objects for importing into simulation and game engine environments.

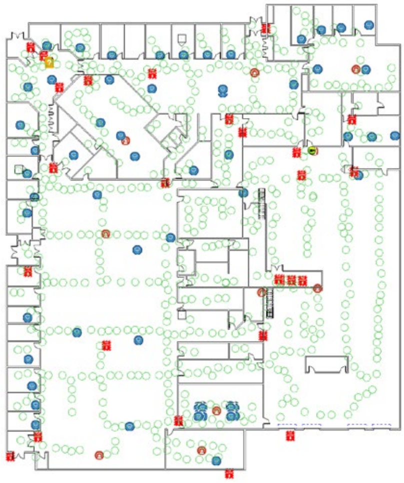
DARPA may select proposers to demonstrate their technologies or methods to determine feasibility of capabilities for potential use in the SubT Challenge in generating and sharing 3D datasets of underground environments.

Such accurately georeferenced data may aid in scoring the SubT competitors' performance in identifying and reporting the location of artifacts placed within the course. In addition, renderings from these data may provide DARPA with additional visualization assets to showcase competition activities in real-time and/or post-production.

Instructions for submissions, as well as full RFI details, are available on the Federal Business Opportunities website: fbo.gov/spg/ODA/DARPA/CMO/DARPA-SN-19-21/listing.html. Submissions are due at 1:00 p.m. EDT April 15, 2019. Please email questions to SubTChallenge@darpa.mil.

Indoor Reality Announces Geo-tagging Capability for Indoor Assets

Berkeley, California—Indoor Reality recently announced the latest update to its 3D mobile mapping solution—capability to associate latitude longitude tags to assets, in GPS denied indoor environments. Unlike tripod based 3D mapping systems, Indoor Reality's suite of mobile mapping systems have been capable of tagging assets either during acquisition, or post acquisition through the web interface. The new feature automatically assigns a lat/long tag to indoor assets, a capability that traditionally has been available only to outdoor assets where GPS is readily available. "The new feature takes asset tagging one step further by providing a unified location identifier for safety, security, energy, and IOT assets, not only inside one building, but also across multiple buildings across the globe. This in turn can be used by asset and



facilities management solutions, and building automation systems to visualize, control, and manage assets seamlessly across multiple buildings. The location meta data is also critical for configuring building automation control and integrating sensor networks. It allows analytics applications to exploit spatial relationship between sensors and devices inside a building, to provide more comfort to the occupants, and to improve building energy efficiency. Furthermore, the geo-tagging information can be integrated with popular GIS software, unleashing the power of GIS software to building interiors." Said Founder and CEO, Dr. Avideh Zakhor.

This feature will become available for current users of Indoor Reality products as of Q2 2019.

Founded in 2015, Indoor Reality is headquartered in Berkeley, California, USA. Indoor Reality's patented hardware and software platforms provide a complete solution for fast, automated, and visual documentation/ 3D mapping of buildings and assets. For more information about Indoor Reality, visit: www.indoorreality.com.

The Demand for Airborne LINX in the European Police Force Grows

Since the release of Airborne Technologies Airborne LINX leading-edge surveillance system, more and more European Police Forces are integrating this capability into their fleets and joining the LINX club.

The latest member to join is the Bulgarian Border Guard. Airborne Technologies was awarded a FRONTEX funded contract to upgrade one of the Bulgarian Border Guard's AW109 helicopters with the Airborne LINX system. Besides the integration of Airborne LINX, the platform will be high-end equipped with a FLIR Star Safire 380 HD, an ECS Line of Sight Downlink and a payload friendly carbon fibre tactical workstation.

Wolfgang Grumeth, CEO of Airborne Technologies, said: "We are proud that Airborne LINX is on the rise amongst Europe´s Police Forces. With the Bulgarian Border Guard, a further European authority trusts our experience and our innovative solutions. In the meantime, aircraft—rotary and fixed wing—with our surveillance technology on board are on duty for numerous police forces all over Europe. With the AW109 missionized with Airborne LINX, the Bulgarian Border Guard will be one of the best-equipped police forces in Europe. Welcome to the club!"

Bluesky 3D Models Improve Mobile, 5G and Smart City Network Planning

Leicestershire, UK—3D digital models derived from high resolution aerial photography are helping network operators plan the rollout of services including WISP (Fixed Wireless Access), 5G and Smart City applications. The work by Leeds based Wireless Coverage uses Digital Terrain and Surface (DTM / DSM) models. Derived from Bluesky's aerial photography, the models are used within Wireless Coverage's WISDM software which uses GPU Acceleration technology to create dynamic coverage maps. These maps are already being used to help operators plan network infrastructure, undertake property level look-ups and conduct marketing campaigns.

"Recent jumps in wireless technology allow huge uplifts in speed of data access and, in the UK alone, it is estimated that over 200,000 new small cell sites will be required to service the increase in data demand and new applications such as autonomous vehicles," commented David Burns, founder of Wireless Coverage, the Chairman of the UK Wireless Internet Service Providers Association (UKWISPA) and an active member of 5GUK.

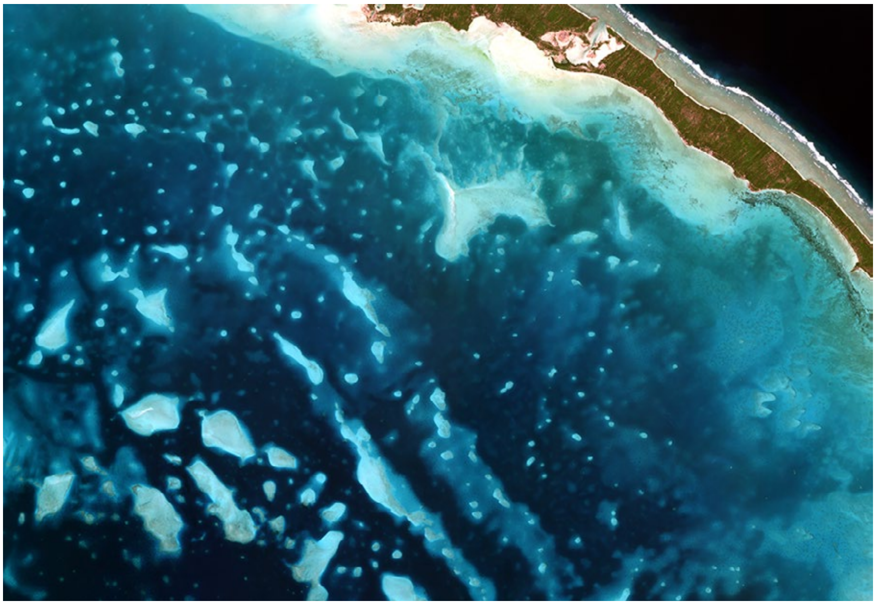
"Conventional planning tools are not designed for 5G and the very high frequencies in which it operates. These super high—millimetre-wave—frequencies are extremely susceptible to obstructions, such as buildings and trees, so highly accurate data and more precise planning systems are required to deliver reliable services," he continued. "Bluesky's national coverage of high resolution terrain and surface data, together with our WISDM solution, combine to solve this problem."

Wireless Coverage has successfully implemented the massive scale and performance of wireless-optimised GPU (Graphics Processing Unit) technology into wireless design. WISDM can perform billions of wireless line of sight calculations per second, meaning that large areas can be modelled, in high resolution, in real time. Using WISDM network operators can produce dynamic, scalable coverage maps based on the terrain and surface obstructions detailed within the Bluesky data, and the propagation patterns of access points.

Site planning functionality within WIDSM allows assessment of backhaul from other sites and an understanding of which properties can be served and advanced modelling features allow testing of different locations and antenna heights. WISDM can also be used to find intermediate locations to bridge existing towers or customers.

"Bluesky's unique and highly accurate DTM and DSM's enable the power of WIDSM to be unlocked," concluded Burns. "For the first time, network planners can design wide-area Radio Access Networks using data resolutions of 50 cm, in real-time. This speeds up the design process, allows changes to be accommodated instantly and reduces coverage risks compared to conventional solutions."

Bluesky is a specialist in aerial survey including aerial photography, LiDAR and thermal data, using the very latest survey technology, including two UltraCam Eagles and a Teledyne Optech Galaxy LiDAR system integrated with a PhaseOne camera and thermal sensor. An internationally recognised leader with projects extending around the globe, Bluesky is proud to work with prestigious organisations such as Google, the BBC and Government Agencies. Bluesky has unrivalled expertise in the creation of seamless, digital aerial photography and maintains national "off the shelf" coverage of aerial photography, DTM and DSM through an ongoing three-year update programme. By purchasing a world first sensor for the simultaneous capture of LiDAR, Thermal and Aerial Photography data, Bluesky is in the enviable position of being able to provide customers with unique and cost effective solutions. Bluesky is leading the way in developing innovative solutions for environmental applications, including the UK's first National Tree Map (NTM), solar mapping and citywide 'heat loss' maps and is currently developing noise and air quality mapping products. Bluesky is also the first company to offer CityMapper (simultaneously captured vertical, oblique and LiDAR) data in the UK. bluesky-world.com.



The Kiribati project highlights the efficiency and cost effectiveness of SDB technology in a geographic area too remote and enormous for traditional marine or airborne survey methods.
Credit: DigitalGlobe

TCarta Wins Contract to Map Seafloor around Remote Pacific Island Nation

Denver, Colorado—TCarta Marine, a global provider of geospatial products and services, has been contracted by the United Kingdom Hydrographic Office (UKHO) to provide a baseline dataset of water depths and seafloor classification around the Republic of Kiribati. Located in the Pacific Ocean, the island nation is threatened by rising sea levels.

"Most of Kiribati's islands average less than two meters above sea level at present and the country's 110,000 inhabitants are among the most vulnerable to the effects of sea level rise and the world's first potential climate change refugees," said Kyle Goodrich, TCarta President. "We expect to map 5,000 square kilometers in total. Our seafloor maps will be used with other geospatial information by the UKHO to recommend policies that will assist the Kiribati in planning for and responding to this situation."

TCarta won the open bid for supply of Satellite Derived Bathymetry (SDB) to the UKHO to extract water depth measurements and seafloor classifications, including habitat types, from multispectral satellite imagery. In this project, TCarta is processing eight-band DigitalGlobe WorldView-2 and -3 data predominantly, as well as four-band WorldView-4 and GeoEye-1 data to measure depths down to 30 meters at a resolution of two meters.

"The Kiribati project highlights the efficiency and cost effectiveness of SDB technology in a geographic area too remote and enormous for traditional marine or airborne survey methods," said Goodrich.

The Kiribati nation is comprised of 33 atoll islands and multiple reefs spread over an area of the Pacific Ocean nearly the size of the Continental U.S. Multiple new reefs have been discovered by TCarta using this satellite derived approach at the start of this project. The islands and surrounding environs have not been mapped in their entirety since the late 1800s. Acquiring bathymetric data and habitat classifications using traditional ship-borne SONAR or airborne LiDAR are prohibitively expensive, logistically challenging and come at far higher cost and timeframe than a satellite-based solution.

"We began tasking the DigitalGlobe satellites to capture images in December and will deliver the final products to the UKHO in early March," said Goodrich, "DigitalGlobe has been a tremendous partner in helping TCarta meet the project deadlines and challenging open ocean conditions with repeat tasking of imagery, collecting more than 300 images in support of the project, despite the loss of WorldView 4."

For nearly 10 years, TCarta has been delivering accurate SDB surveys in projects related to oil & gas production, infrastructure development, and environmental monitoring along coastal regions around the world. A differentiator in TCarta's winning the UKHO contract was the company's leadership role in developing more advanced bathymetric measurement technologies using satellite data. Funded by the National Science Foundation SBIR Phase I grant and known as Project Trident, this new technology is being deployed in the Kiribati project to remotely validate the bathymetry results.

TCarta was established when TCarta Marine U.S. merged with Proteus Geo UK to create global bathymetric and marine datasets extending from the shallow coastal zone to the continental shelf. The international firm maintains offices in Denver, Colorado, and Bristol, UK. The TCarta product lines includes high-resolution satellite-derived water depth and seafloor map products as well as 90- and 30-meter GIS-ready bathymetric data aggregated from numerous information sources.

Bluesky Aerial Photographs Reveal Hidden Irish Archaeological Sites

Cork, Ireland,—The National Monuments Service in Ireland is using high resolution aerial photography from Bluesky to map and investigate a giant 4,500 year old Henge. The circular structure, located the Brú na Bóinne UNESCO World Heritage Site, is evidence of prehistoric earthworks and was first observed by researchers with drones. Following the discovery, the National Monument Service of the Department of Culture, Heritage and Gaeltacht carried out extensive aerial reconnaissance including commissioning Bluesky Ireland to survey the cropmark enclosure at Newgrange.

"This new information is a graphic illustration of the extent and density of the ritual and ceremonial sites associated with the Newgrange Passage Tomb," commented Joseph Madigan, T.D., Minister for Culture, Heritage and the Gaeltacht. "This stunning new archaeological data provides fresh, spectacular and unique insights into the origins and development of the Neolithic landscape and society."

The summer of 2018 was unusually dry with near drought conditions during June and July, conditions which had already revealed crop marks of ancient castles and Iron Age forts in England and Wales. Researcher and photographer Anthony Murphy therefore decided to fly his drone over the Boyne Valley and located a large, circular crop mark in open farmland, indicating the presence of buried archaeological features.

Following the initial discovery the NMS used a Geographic Information Systems (GIS) to organise views of the landscape across maps, photographs and drawings of cropmarks identified to date. The location of the newly identified site was also visited to enable a better understanding of the topographical locations and the physical and visual relationships between sites.

NMS also availed itself of historic imagery and commissioned aerial mappings specialist Bluesky Ireland to capture the most up-to-date and detailed view of the landscape and discoveries. Bluesky also supplied 3D height measurements in the form of a 1 metre resolution Digital Terrain Model (DTM) which is being used alongside various layers of mapping including Ordnance Survey data.

A newly published report—The Archaeology of the Brú na Bóinne World Heritage Site Interim Report—details new information on the discoveries. Reinforcing the remarkable level of ceremonial and ritual use of the landscape during the prehistoric period up to 5,000 years ago, immense enclosures of timber uprights and large henges have been identified. These monuments, visible only fleetingly as cropmarks during the dry summer and recorded by Bluesky, clearly form a deliberately structured and ritual landscape of great significance.

Bluesky Ireland is a specialist in aerial survey using the very latest technology to capture and process aerial photography and LiDAR. Bluesky Ireland offers unrivalled speeds of capture coupled with high accuracy and quality, underpinned by more than 30 years' experience in aerial surveying. Having begun an ambitious national data capture programme in 2015, Bluesky Ireland has captured high resolution aerial photography of a significant area of the country, with surveying expected to be completed in 2018. Bluesky Ireland is already working with many high profile organisations in the Irish geospatial market including the Department of Agriculture, Food and the Marine, the Department of Culture, Heritage and the Gaeltacht, the Geological Survey of Ireland and the state forestry company Coillte, as well as a host of local authorities. www.bluesky-world.ie

Bluesky Geospatial—trading as Bluesky Ireland—is a wholly owned subsidiary of Bluesky International and part of the global Bluesky organisation which also includes Col-East in the USA and Bluesky Geotech PVT, India. www.bluesky-world.com

Aerial image Bluesky International Ltd and DTM created by Discovery Programme / Meath County Council

Introducing the senseFly eBee X with MicaSense RedEdge-MX, a seamless dual solution for accurate and efficient crop analysis

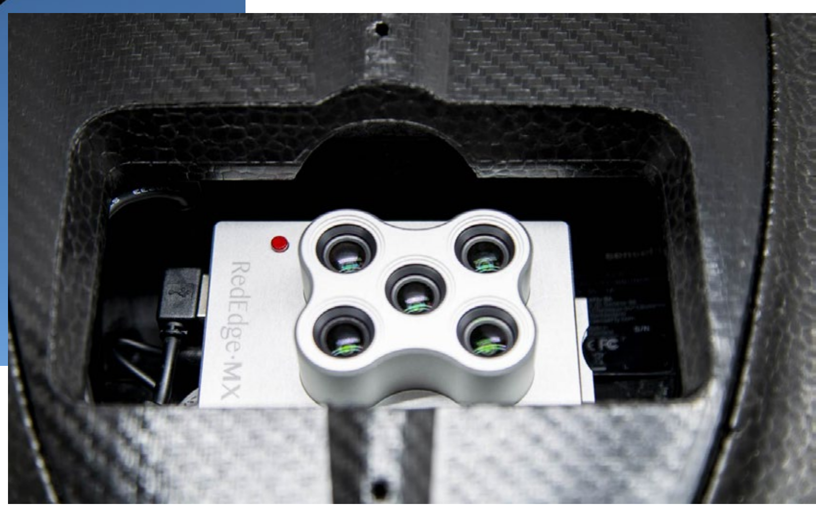
The sensor that doesn't compromise meets mapping without limits. New dual solution enables farming, agricultural science, forestry and environmental protection professionals to gain valuable multispectral crop insights more efficiently than with slower, smaller-coverage multirotor drones

Cheseaux-sur-Lausanne, Switzerland—senseFly, the leading provider of fixed-wing drone solutions, and MicaSense, a leading producer of drone sensors for agriculture, has announced a new dual solution for efficient, in-depth crop analysis—the senseFly eBee X with MicaSense RedEdge-MX.

"We know from agricultural customers such as agronomists, crop consultants and researchers that deep, high-resolution crop data is key to effective analysis and decision making," said Gilles Labossière, CEO of senseFly. "In parallel, when assessing large field areas, or simply looking to map smaller fields or plots quickly, small, slower quadcopter drones often don't cut it. The eBee X with RedEdge-MX checks both these data and efficiency boxes, making it an ideal crop analysis solution."

"This seamless, integrated professional drone offering represents an obvious upgrade path for many agricultural professionals. Customers who already use MicaSense's RedEdge-MX, for example, now have a quicker, more efficient way to analyse the health of their crops, without having to compromise on data quality," said Eric Waters, General Manager of MicaSense. "At the same time, existing eBee X operators can access the deeper, higher resolution insights that the RedEdge-MX brings."

The RedEdge-MX is a rugged, built-to-last professional multispectral sensor. Capturing red, green, blue, near-infrared, and red-edge spectral bands, data from this sensor can be used to generate true color composites, basic crop health indexes, and advanced analytical tools like flower identification and weed detection. This, in combination with its durable design, makes RedEdge-MX a multispectral powerhouse.



Key benefits include:

- The ability to capture plant health images & RGB (composite) images in one flight
- A fast capture rate, which suits faster fixed-wing flight speeds
- Global shutter on all five lenses for distortion-free images
- High-resolution imagery; 8 cm (3.1 in) / pixel GSD at 120 m (400 ft) flight height
- An aluminium body for better durability and performance in the heat
- Full access to raw data; generate outputs using a wide variety of processing & analysis platforms
- Patent pending DLS 2 for highly accurate radiometric calibration

The senseFly eBee X fixed-wing drone is designed to boost the quality, efficiency and safety of commercial UAV operators' data collection. Its key features include:

- A unique Endurance Extension option, which unlocks a flight time with RedEdge-MX of up to 75 minutes (versus a maximum endurance of 59 minutes by default) for single-flight coverage of up to 220 ha (540 ac)
- The ability to work every site, no matter how challenging, thanks to the drone's built-in Steep Landing technology, ultra-robust design, live air traffic data and more, all backed by senseFly's professional, localised support
- A range of professional camera options, including the MicaSense RedEdge-MX, and the new, proprietary senseFly S.O.D.A. 3D, senseFly Aeria X, and senseFly Duet T.

The senseFly eBee X with MicaSense RedEdge-MX (including plug-and-play camera integration kit, Downwelling Light Sensor (DLS2), and Calibrated Reflectance Panel) is available for purchase now via senseFly distribution partners. It is priced at $19,800 USD excluding shipping and importation taxes.

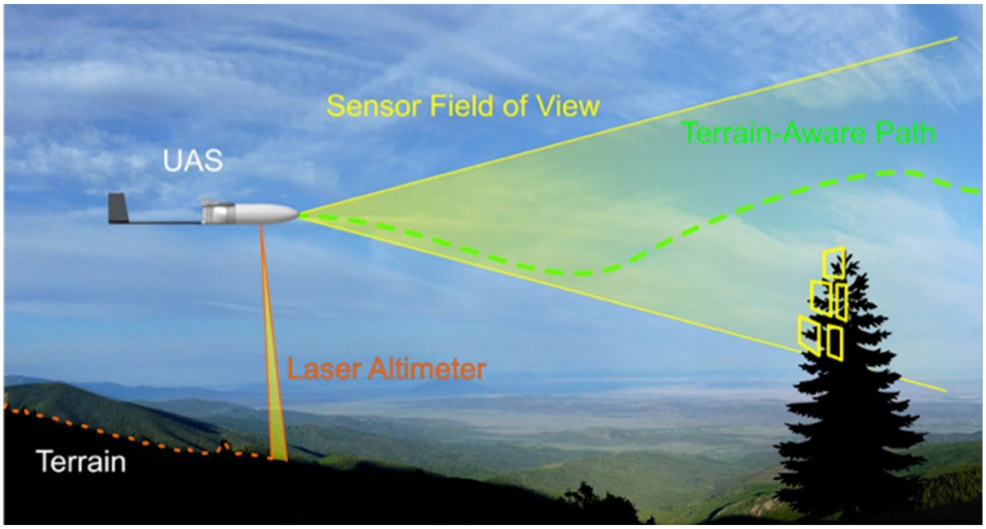
Schneider Digital—The company:

Schneider Digital is a global, full-service solution provider for professional 3D stereo, 4K and VR / AR hardware. With over 20 years of industry and product experience and excellent relationships with leading manufacturers, Schneider Digital offers products and solutions for professional use. We offer qualified consulting, innovative and sophisticated professional hardware products, complete tailor-made solutions and committed after-sales service.

The Schneider Digital product portfolio includes the right professional hardware solution for all requirements in each product area—high resolution 4K monitors (UHD), 3D stereo and touch monitors with up to 4K resolution and sizes from 27" to 98", VR / AR solutions from desktop systems to Power Walls and Multi-Display Walls, professional AMD FirePro / Radeon Pro or NVIDIA Quadro graphics cards, performance workstations and innovative hardware peripherals (tracking, input devices etc.). Schneider Digital manufactures its own Powerwall solution (smart VR-Wall) and the passive 3D stereo monitor 3D PluraView.

Schneider Digital products are primarily used in graphics-intensive computer applications such as CAD / CAM / CAE, FEM, CFD, GIS Geo-information systems, architectural, research, medical, animation, film, TV and digital imaging. Thanks to its excellent contact with leading manufacturers, Schneider Digital has extensive expertise and detailed knowledge in designing individual solutions for a wide range of applications. An extensive, stocked product portfolio guarantees fast delivery and project implementation. Schneider Digital is an authorized service distributor of AMD FirePro and Radeon Pro, PNY / NVIDIA Quadro, 3Dconnexion, Stealth int., Planar and EIZO.

More information at schneider-digital.com, vrwall.com and PluraView.com.



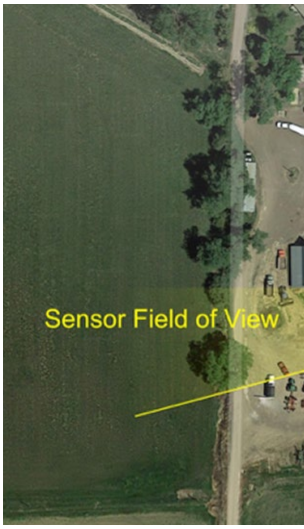


Figure 1: Terrain Following Overview

Black Swift Technologies Developing Active UAS Navigation

Enables Fixed-Wing UAS to Fly Autonomously Around Obstacles and Over Rugged Terrain

Boulder, CO—Black Swift Technologies (BST), a specialized engineering firm based in Boulder, CO, announced it has completed the first phase of a NASA-funded project to demonstrate the effectiveness of fusing a host of onboard sensors to develop a terrain-following fixed-wing unmanned aircraft system (UAS), in this case, it will be demonstrated using the Black Swift S2™ UAS.

BST's understanding and integration of artificial intelligence (AI) and machine learning can help serve as a catalyst for accelerating UAS growth and adoption, industry-wide. Through autonomous, active navigation around obstacles and over rugged terrain by a fixed-wing UAS, BST is demonstrating how technology can help make UAS operation simpler and safer, for both operators and the public.

"Our state-of-the-art sensor suite and approach to sensor fusion enables a number of capabilities not yet seen for fixed-wing UAS," says Jack Elston, Ph.D, CEO Black Swift Technologies. "Integration of these developments with our highly capable avionics subsystem can make flying a fixed-wing small UAS significantly safer for operations in difficult terrain or beyond line of sight."

Relevance of the Technology

Fixed-wing aircraft can scan substantially more area in less time than their multi-rotor counterparts. Yet low altitude sensing by fixed-wing UAS is not without its challenges. Avoiding obstacles such as trees and towers, along with terrain variations that can exceed the climb capabilities of the aircraft, are some of the inhibitors to widespread use of fixed-wing aircraft for scientific and commercial data gathering operations (**Figure 1**).

BST's solution fuses state-of-the art machine vision technologies with advanced sensors, including lidar and radar, into a modular subsystem enabling a fixed-wing UAS to operate safely in a variety of theaters and weather conditions.

While initial deployments will focus on fixed-wing UAS, initially the Black Swift S2, this subsystem of augmented onboard intelligence will be extended to multi-rotor UAS as well as other UAS platforms in future iterations.

Beyond Terrain Following to Obstacle Avoidance

The last few years have seen significant growth in collision avoidance technology for multi-rotor vehicles. This has not only driven the miniaturization and diversification of proximity sensing suites, but also spawned a number of technologies for providing onboard image processing and data fusion. While some of these technologies are applicable to fixed-wing collision avoidance, the relatively low speeds of average multi-rotor UAS and their ability to hover in place have generally produced shorter-range

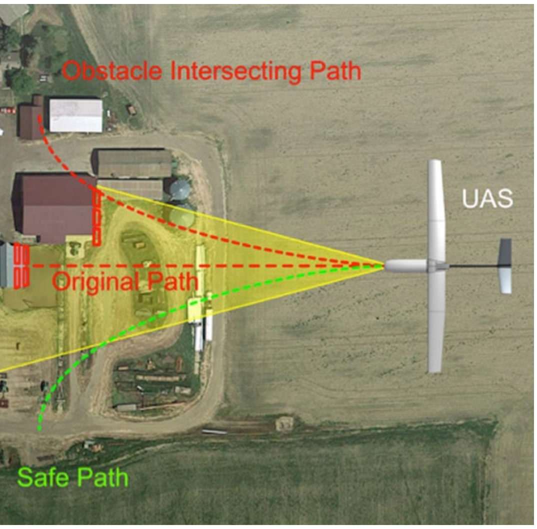


Figure 2: Obstacle Avoidance Overview

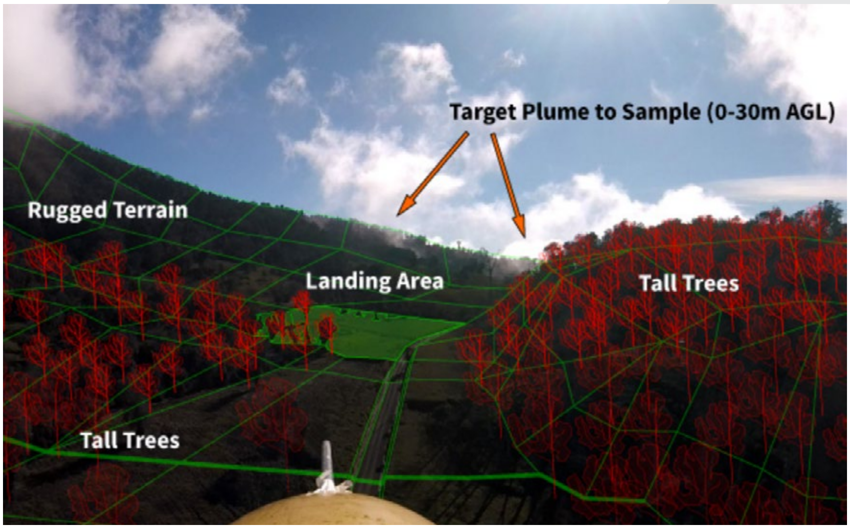


Figure 3: Data-Centric Flight Control

proximity sensing solutions. The dynamics and relatively high speed of larger fixed-wing UAS require much longer range sensing and predictive real-time avoidance decision processing capabilities to give the aircraft sufficient time to react.

Recent advancements in self-driving cars and advanced driver assistance systems (ADAS) for automotive applications have resulted in a variety of longer-range sensors including radars and lidars. This project fuses common vision-based techniques with both lidar and radar, enabling fixed-wing UAS data gathering flights in a wide breadth of environments.

In instances where an inflight emergency is encountered, especially when the UAS is flying beyond-visible-line-of-sight (BVLOS), remote and autonomous landings can be safely achieved leveraging the systems' online machine vision classifiers. These classifiers can accurately and effectively identify obstacles (people, buildings, vehicles, structures, etc.) that could impede finding a viable, and safe, landing area (**Figure 2**). The result is an autonomous and remote landing without causing detrimental impact to people or property.

Applications

Many application areas of UAS demand the use of a vehicle able to cover a larger sampling area, such as pipeline and other infrastructure inspection, rock and mudslide monitoring, snowpack analysis, forest biofuel calculation, invasive plant species identification, trace gas emission observation over volcanoes, and missions requiring high-resolution imagery.

Using a UAS capable of carrying the necessary instruments routinely through difficult environments adds an invaluable contribution to the calibration and validation of data collected from ground- and satellite-based methods. This use of active remote sensing (sending out a signal that interacts with the environment and the resulting changed signal gets detected) allows data collected from a UAS to enhance comprehensive 3D models more effectively than traditional remote sensing methods.

In the case of volcano monitoring, low-AGL UAS flights (following the terrain of the forest canopy) enables the vehicle to directly sample gas plumes and ash clouds that are low to the ground, where the richest chemical and physical characteristics exist immediately after eruptions (**Figure 3**).

The use of a UAS to measure hazardous phenomena, such as wildfire smoke, eliminates the risk of harm to researchers and scientists making observations at close proximity. Utilizing UAS systems provides researchers the ability to collect desired data sets while remaining at a safe vantage point from the danger posed by the phenomena.

Catalyst for UAS Growth and Adoption

Black Swift's system allows for active navigation around obstacles and rugged terrain by fixed-wing UAS, thus reducing adverse impact to either people or property.

By making UAS operation safer—for both operators and the public—BST's understanding and integration of AI and machine learning can help serve as a catalyst for accelerating UAS growth and adoption, industry-wide.

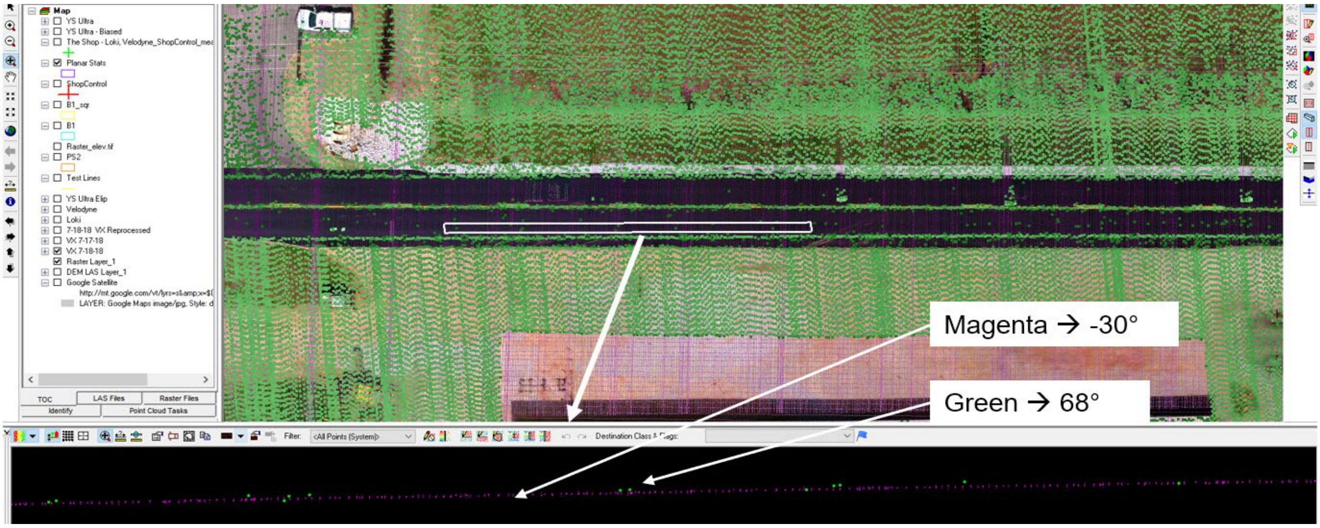


Figure 2: Effect of beam slant on receiver sensitivity.

Graham, *continued from page 48*

over paint stripes. Secondly, notice that these points are at the wrong elevation. They are higher than the road surface (I measured this at an average value of 8 cm).

The conclusion here is to be wary of system integrator specifications on lidar performance. Just because you can hip shoot points at 70° off nadir does not mean you should! In fact, my back of the envelope recommendation is to limit the useable portion of a swath to no more than 45° off-nadir.

As mentioned, I intend (one of these days!) to create a white paper on interpreting specifications for UAV lidar systems. Perhaps I can even persuade Stewart to publish it in this magazine as a proper article!

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LEWIS GRAHAM

Wide Angle Blues ...

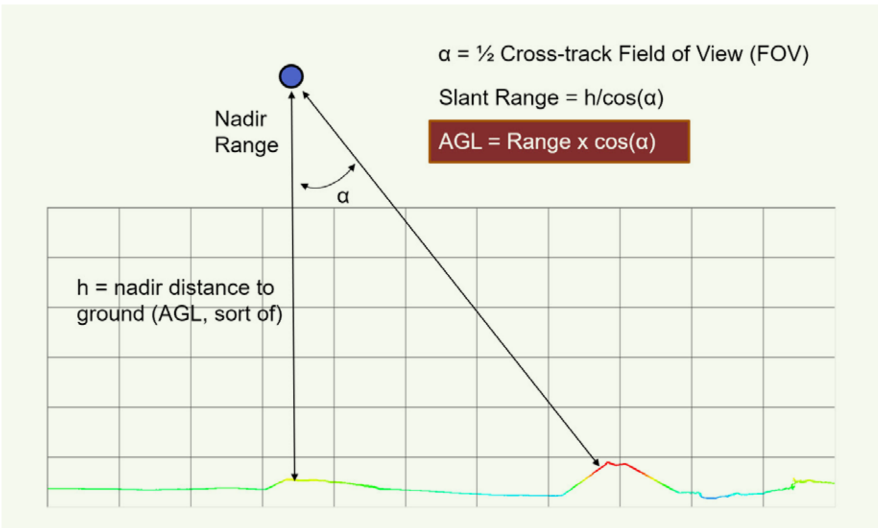

Figure 1: lidar Slant range.

I just gave a talk at the International lidar Mapping Forum (ILMF) conference in Denver on interpreting specifications of UAV lidar systems. I promised a few folks that I would write a white paper on the topic and they took me up on the offer. To get started on this task (which I know will be a long time coming), I though I would devote this month's column to considerations of UAV lidar systems that are capable of a very wide-angle field of view (FOV).

Lidar scanners originally designed for mobile mapping or automotive applications (such as Velodyne) are now being adopted as airborne laser scanners for UAV deployment. These scanners often use either a set of fixed laser diodes on a rotating spindle or a single laser steered by a rotating mirror. As such, they offer a 360° or near 360° FOV.

> "Just because you can scan a wide angle FOV doesn't mean you should!"

This is fine, though much of the data is wasted since the scanner is imaging the bottom of the UAV and/or the sky. The problem comes in when you examine the specifications some of the scanner integration companies are promoting. Let's dive in to this a bit.

The useful range of a lidar system is the distance from the sensor to the point where the beam intersects the object of interest (typically the ground). This is not the flying height of the UAV (Above Ground Level, AGL) but rather the *slant range* to the ground (**Figure 1**).

Now the problem is several lidar integrators indicate that you can increase swath width by simply lowering AGL. For example, suppose you have a lidar with a specified range of 100 m. If you let the off-nadir angle increase to 65° and fly at an AGL of 42 m, all should be good since the slant range at 65° will be 100 m. I have actually seen plots in lidar integrator manuals that show swath width versus AGL based on this sort of flawed logic.

The flaw in this thinking is the fact that a laser beam diverges as it travels out from the emitter. For example, the spot size of a Riegl miniVUX at 100 m is 16 cm (it is not really round but that does not matter for this discussion). If the beam makes an angle with respect to the ground, the spot elongates into an oval with the major axis in line with the beam. This phenomenon reduces the beam energy per unit area (since the area is increased), significantly impacting the range detection sensitivity of the scanner.

The result of this phenomenon is illustrated in **Figure 2**. The rectangular white box positioned over the road in the plan view is sampling data for the profile view. Inside this rectangle, points in green are at about 68° off nadir whereas those in magenta are about 30° off nadir.

Notice several problems with these data. First of all, we are getting very few returns from the 68° data (green) except

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