VOLUME 8 ISSUE 5

LIDAR MAGAZINE

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Image created using eCognition® software from Trimble.

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

DR. A. STEWART WALKER

Summer highs

I had the privilege, along with publisher Allen Cheves and professional land surveyor Jason Foose, County Surveyor, Mohave County Public Works, Arizona, to represent *LIDAR Magazine* at the spectacular HxGN LIVE 2018 event in Las Vegas in mid-June. This was the first time I had attended this event and it was the real thing, orchestrated, up-beat and packed with information. There were more than 3500 attendees from 70 countries. The event made a big impression on me. Early on, the press were taken on a tour backstage to see the massive audiovisual effort behind the big keynotes—enormous screens, duplicate projection systems, lots of people who knew what they were doing. As we waited for CEO Ola Rollén to take the stage, smoke swirled around but I didn't see any mirrors! Starting from a concise description of Netflix eclipsing Blockbuster Video, Ola introduced pillars of disruption then moved on to Hexagon innovations such as the Exalt "platform of platforms" and the autonomous connected ecosystem. As the days hurried by, we became used to senior executives in snug designer suits and no ties striding on to the stage and giving almost flawless presentations without notes. I asked Hexagon Geosystems president, Jürgen Dold, how businessmen develop this expertise. He assured me that it is just hard work and practice and his own keynote was unsurprisingly excellent. He came on stage with a backpack, from which he unveiled the new BLK3D and RTC360 products. It's now 49 years since I first came in contact with the industry, as a rodman on construction sites, but only now do I realize that what I was doing was reality capture! Many of the keynotes, as well as the conference summaries, are on YouTube—take a look!

Shortly afterwards, Allen attended the Esri International User Conference in San Diego, a bigger and similarly polished performance. The rise of user conferences, run by big suppliers such as Esri, Hexagon and Trimble, as well as lots of smaller ones such as Blue Marble and nFrames, raises interesting questions. Do these supersede, compete with, or not affect traditional conferences? Given the limited budgets of attendees, the third of these is unlikely. Critics may decry user conferences as no more than congregations of customers consuming "Kool-Aid"; while vendor staff give the big presentations and there are multiple vendor presentations and exhibits, however, there are also numerous excellent, not necessarily parochial, customer presentations and fine exhibits from partner companies. Remember, too, that many of them are replicated, at a smaller scale, at the regional, national or lower level. The user conferences, therefore, have reduced the number of general conferences that vendors' customers can attend each year, resulting in a consolidation of conferences, producing fewer, bigger, more vibrant, more successful events that draw bigger audiences. Examples already mentioned in these

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SPATIAL MEDIA

USIBD U.S. Institute of BUILDING DOCUMENTATION


Strengthening
our infrastructure,
one project at a time.

editorials are ILMF/ASPRS and SPAR 3D/AEC Next. C-level executives must breathe sighs of relief that their managers and other professionals can update effectively with less investment in labor days and travel. We seem to be headed in the right direction.

Some issues ago, we published an article based on my visit to Cepton Technologies, an automotive lidar start-up in Silicon Valley. Cepton recommended that I talk to one of their customers, May Mobility, which uses autonomous vehicles for "community-scale fleet transportation" for its customers. I visited them and the article is in this issue. Each vehicle, however, has a human attendant, ready to pounce on a custom-built T-bar that activates a drive-by-wire control system, if the unexpected arises. This inspires customer confidence, rather like the elevator attendants in department stores of my youth, yelling exotic attractions, such as "haberdashery" and "millinery", as the doors opened. Perhaps more exciting to readers, though, is May Mobility's use of sensor fusion: they depend on a vast number of sensors and use the data from them not only for vehicle control but also for database update when the vehicles return to the operations center for charge. I've been espousing sensor complementarity and this case is an exemplar. While automotive lidar is not the first focus of this magazine, we acknowledge that the huge market size—millions of vehicles per year—is extremely likely to motivate innovations beneficial to the ALS, TLS and MMS worlds, so we keep an eye on it. *The New York Times*[1], for example, recently ran an article about the debates taking place in cities over schemes such as May Mobility's. Will they work at all? Will they really outperform buses or Ubers? Should New York City repair its ailing metro or cover the tracks in concrete and fill the tunnels with "platoons" of AVs? The problem is that the specter of AVs is a disincentive for cities to invest in conventional transportation, so existing infrastructure deteriorates or remains inadequate. Some players liken this dilemma to that 80 years ago when freeways were the innovation fighting for investment with conventional solutions. Is it OK to do nothing while cities wait to see how the technology evolves? The debate abounds with smart participants, yet the answers are frustratingly elusive.

In the last issue I raised the arcane topic of lidar in fiction and had to concede some ground to cartography, which is better represented. Another cartographic hero paces the pages of a short story by the celebrated Australian author, Peter Carey, entitled "'Do You Love Me?'", which is set in an imaginary world governed by the Cartographers, whose mapmaking can control activity in the real world.[2] Intriguing!

LIDAR Magazine's new website is up and running, easier to use and much more visually appealing than its predecessor. All issues of the magazine are available there, but provides a lot more besides, such as press releases and other news. We can offer customers combined print/digital opportunities and guarantee our writers more exposure. Navigate to lidarmag.com and enjoy!

I am indebted to Wendy Lathrop, doyen of journalism on our sister magazine *The American Surveyor*, for drawing my attention, just as this editorial was going to press, to a piece in *The Press of Atlantic City*[3], about a "bright yellow, boat-like buoy that floated off a dock at Gardner's Basin[, which] will use high-tech instrumentation on deck to help Danish offshore wind company Orsted place wind turbines for its Ocean Wind project, planned for 10 miles off Atlantic City." It continues, "The most important equipment on the buoy is the FLiDAR, or Floating Lidar, unit on board. It shoots lasers up to 200 meters in the air to take wind speed and direction measurements, said P.S. Reilly, president and CEO of Axys Technologies, which developed the buoy." Wendy, of course, homes in on the big issue, whether we would prefer "flidar" or "Flidar", but argues that these visually appear as something completely unrelated to the real measurement tool involved. Pedants will relish this dilemma, but I wonder whether it's early days yet and the acronym will evolve into something else if usage rapidly accelerates…

A. Stewart Walker // Managing Editor

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LIDAR
LEADER AWARDS
BROUGHT TO YOU BY
ILMF & LIDAR MAGAZINE

MAKE YOUR NOMINATIONS

for the 2019 Lidar Leader Awards

International LiDAR Mapping Forum (ILMF) and *Lidar Magazine* are excited to announce the second annual Lidar Leader Awards, which will be presented at ILMF, taking place January 28-30, 2019 in Denver. This is an exciting opportunity for the geospatial community to recognize the amazing work being done every day by professionals like you.

The joint effort between ILMF and Lidar Magazine will honor some of the people working with lidar technology who have made a significant impact on the industry. We invite you to nominate an individual, organization, project, innovation or university accomplishment. It is an excellent opportunity to showcase innovative strategies and gain recognition among industry peers for some *outstanding* work. You may submit nominations to any of from five distinct categories:

Outstanding Personal Achievement in Lidar

Outstanding Team Achievement in Lidar *(2-99 members)*

Outstanding Enterprise Achievement in Lidar *(Groups of 100+)*

NEW FOR 2019!

Outstanding Innovation in Lidar

Outstanding University Achievement in Lidar

If you know of a group, person, project, innovation, or university that should be considered for a Lidar Leader Award, take a moment to review our submission criteria and nominate them at: ***www.lidarmap.org/lidar-leader-awards***

The winners will be recognized and presented with their award during an awards ceremony at ILMF 2019.

Nominations must be received by **October 15th, 2018** in order to be considered. Please don't hesitate to contact us if you have any questions or recommendations.

MineLifeVR LlamaZOO Data Layers

Maptek and LlamaZOO Bring the Mine to Brilliant Life

August 22, 2018 – A collaborative partnership with LlamaZOO will deliver advanced data visualisation in 3D and VR to mining customers.

Mining technology developer Maptek and augmented reality experts LlamaZOO are teaming together to bring digital twinning and advanced 3D data visualisation to the mining industry.

'At Maptek we're all about building on our legacy of innovative approaches to how customers interact with their technical and operational mine models,' said Maptek Core Technologies Product Manager Chris Green.

'The collaboration with LlamaZOO exemplifies our support of initiatives that really make a difference to industry.'

LlamaZOO Interactive is an award-winning software studio developing 3D interactive data visualisation solutions for enterprise and industry 4.0. LlamaZOO specialises in centralising disparate spatial datasets and making the information actionable for all stakeholders through real-time engaging 3D and VR/AR.

Maptek stakeholders within customer networks will be able to interact with their spatial data in high resolution 3D, in a format typically only seen with high-end video games, but with actionable real-world data.

'Imagine viewing live data, such as trucks and shovels, loaded train cars and material stockpiles, in real-time. Displaying real-time grade control data over scheduling activities provides critical information in context,' added Green.

'Live and interactive simulation of scenarios via a digital twin of the real mining environment can provide surprising insights. Virtually a risk-free mode for decision-making.'

LlamaZOO leverages developing and creating compelling, interactive 3D experiences from the gaming industry to solve real-world problems for innovative companies. LlamaZOO MineLife VR fuses complex geospatial and mine planning data with IoT data into an interactive, life-sized virtual replica of the planned, current, and future states of a mine site.

'Users can explore an entire operation from source to port or facility, see hypothetical scenarios and real-time data, create a variety of presentation media such as 360-degree images, flight paths and export these to other more traditional media access points such as web,' said LlamaZOO CEO, Charles Lavigne.

'Integrating this capability with the artificial intelligence and machine learning development Maptek is already undertaking, synthesises digital data into a powerful, enterprise level solution,' Green concluded.

Maptek™ is a global provider of innovative software, hardware and services. Founded almost 40 years ago to service the mining industry, Maptek offers a unique combination of domain knowledge, technical expertise and engineering resources. We incorporate automated workflows and optimised algorithms to collect, analyse and circulate critical information within the operational cycle, closing the loop between planning, production and results. We develop reliable solutions that allow customers to improve safety, productivity and profitability.

LlamaZOO is an award-winning developer of 3D interactive data visualisation solutions for enterprise and industry 4.0. Co-founders Charles Lavigne and Kevin Oke started LlamaZOO in 2014, bringing extensive experience in the videogame industry with companies such as Microsoft, EA, and Ubisoft. The company's mission is to make big spatial data actionable and understandable for enterprise stakeholders.

Phase One Industrial Launches 150MP Metric Camera and New Aerial Systems

iXM Platform with Advanced Imaging Sensors Delivers Superior Aerial Mapping

COPENHAGEN, August 28, 2018—Phase One Industrial, a leading provider of aerial imaging solutions, today launched the iXM-RS metric camera series and new Aerial Systems. The flagship iXM-RS150F camera is full frame, 150 megapixels and available in RGB and Achromatic models. Its ultra-high resolution (14204 x10652) backside illuminated CMOS sensor, fast capture speed (2 fps) and enhanced light sensitivity enable increased productivity in a wide range of aerial image acquisition projects. The iXM-RS camera is the imaging heart of Phase One Industrial's Aerial System—a fully integrated solution for mapping and surveying.

The two new 150- and 100-megapixel iXM-RS cameras feature Phase One Industrial's proven RS lens series with seven field replaceable focal length options, ranging from 32mm to 150mm. Designed and built for aerial photography by Rodenstock and Schneider Kreuznach, these lenses are factory calibrated for infinity focus and each is equipped with a central 1/2500 sec. leaf shutter.

"Our customers need flexible, efficient imaging solutions for projects that demand superior accuracy and efficiency," said Dov Kalinski, General Manager of Phase One Industrial. "We are committed to helping our customers succeed, therefore we have designed the new iXM-RS camera series and Aerial Systems to exploit the powerful resolution and light sensitivity available from state-of-the-art sensor technology. We aim to deliver the most comprehensive performance for a wide range of photogrammetric applications."

Flexible configurations boost productivity

Phase One Industrial also introduces a new addition to its fully integrated Aerial Systems: a 150MP configuration with either a single frame sensor for RGB imaging or a four-band Aerial System with dual frame sensors for RGB and NIR imaging. Each Aerial System includes the camera and additional components, such as: the iX Controller, Somag stabilizer, Applanix GPS/ IMU unit and the Phase One flight planning and management software iX Plan and iX Flight.

- iX Plan enables users to simply generate flight plans supporting:
  - Digital terrain model (DTM)
  - Base map
  - Project shape
  - Ground control points (GCPs)
- iX Flight uses iX Plan data to manage and guide the precise execution of aerial photography missions.
  - Designed for pilots to easily maintain precise trajectory by following altitude and localizer instructions while the operator manages the mission, control the order of passes, tag images and start/stop image collection;
  - Full control over the camera, stabilizer and GPS/IMU components;
  - Simulation mode for training and system testing.

The new iXM-RS150F and iXM-RS100F single frame cameras introduced today can be used standalone for photogrammetric work, or as part of a multi-camera array for customized applications, including high-resolution oblique camera systems and Lidar systems. They can also be easily integrated with other popular flight management systems and GPS/IMU receivers.

Interfaces and Storage

The Phase One Industrial iXM camera platform supports multiple interfaces for camera controls and storage, including USB-C interface to enable faster yet flexible data transfer or longer cable length with 10G Ethernet (with either fiber or copper options). Also included are local storage with XQD cards, HDMI output with 2K video, and overlays to support high-end integration of UAVs.

For complete technical specifications and a comprehensive view of the new iXM-RS full frame aerial cameras and a complete list of lens options, please see: industrial.phaseone.com/lp/The_New_iXM-RS_150F_Camera.aspx

Availability

The iXM-RS 150MP and iXM-RS 100MP metric cameras in both RGB and Achromatic models and the full line of Phase One Industrial Aerial Systems are all available today for advance order from Phase One Industrial partners worldwide—with delivery expected in September 2018.

For more information regarding purchase options for cameras, lenses and software and for partner locations, please contact us at: industrial.phaseone.com/Contact.aspx

The Phase One Industrial iXM-RS 150F camera as well as both 150MP and 100MP Aerial Systems will be on view at Intergeo Conference, Messe Frankfurt, Germany on October 16-18, 2018. Please visit Phase One Industrial at: Hall 12.1, Booth # 12.1D.012

Phase One Industrial is a division of Phase One A/S that researches, develops, and manufactures specialized industrial camera systems and imaging software solutions. The division focuses on specific applications such as aerial mapping and surveying, ground and aerial inspection, agriculture, machine vision and homeland security. industrial.phaseone.com

FARO Announces SCENE 2018 with FARO Laser-HDR and High Detail Scanning

Enhances Traceable Construction for AEC

Lake Mary, Fla., Aug. 28, 2018 — FARO® (NASDAQ: FARO), the world's most trusted source for 3D measurement and imaging solutions for construction BIM, announces the release of SCENE 2018 (faro.com/scene), a tightly integrated software platform specifically designed for the FARO Focus Laser Scanner product family. This introduction represents a substantial leap forward for 3D reality data capture and the FARO-driven concept known as Traceable Construction™, in which optimizing the entire AEC construction lifecycle is accounted for in the solution's strategy, development and execution.

A New Standard in HDR Photography

The new FARO Laser-HDR™ (patent pending) feature in SCENE 2018 improves on conventional multi-exposure HDR techniques by intelligently combining a laser scan image and a photograph through a proprietary FARO process. This results in a laser enhanced HDR image in breathtaking color and detail in even the most challenging environments. This advanced feature is fully backwards compatible and thus allows all generations of FARO Focus Laser Scanner products to achieve exceptional HDR results in a considerably shorter amount of time. Finally, even as recording time (5X faster than traditional HDR) and data volume are dramatically reduced (150 MB per scan), all image details are captured in a single shot and the functionality can be used even if the laser scanner does not support HDR by default.

Increased Productivity Through High Detail Scanning

Defined areas, such as registration marks, can now be recaptured in higher resolution at a great distance from the same scanning position. FARO Focus S150 and S350 users now benefit from significant time savings on site, at least 1.5X faster than when it was required to perform high-resolution scans continuously. Furthermore, since the registration workflow is now fully automated (i.e., no manual interaction needed to process high detail scan data on an onsite PC/workstation), in-field and in-office productivity is improved even more substantially.

Efficiency Through Full Color Panoramic Images

SCENE 2018 enables a full camera resolution color image to be exported, independent of scan resolution. In those situations where high resolution color is required but high resolution scan is not, time savings of up to 80% can be realized.

Improved Performance and Stability

Scan quick views now open significantly faster and users can be ready to work with the data in half the time than before. Scan projects can be exported up to 75% faster to be shared more efficiently with project stakeholders via the FARO WebShare Cloud and SCENE 2go platforms.

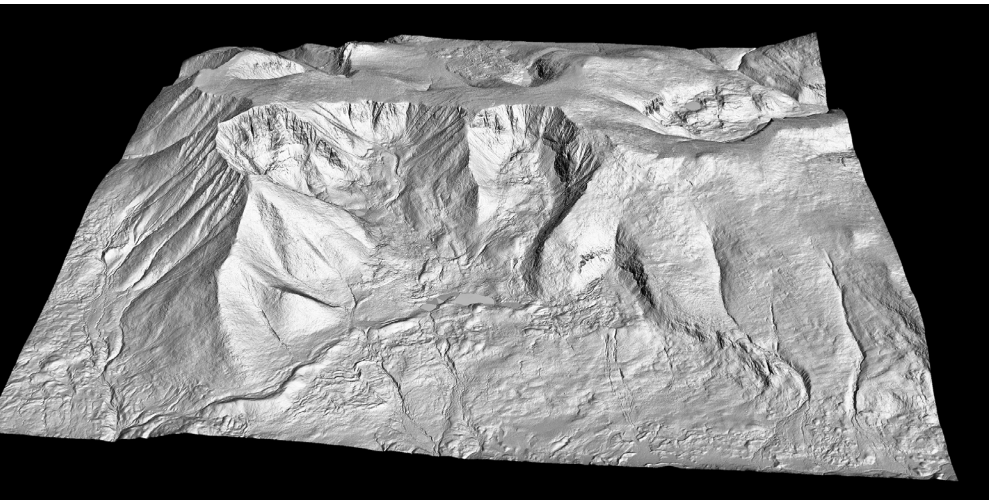
Enhanced Virtual Reality (VR) Experience

SCENE 2018 builds on the VR base first introduced on SCENE 7.1 in 2017. First, it enables an even more natural, immersive experience with significantly fewer instances of motion sickness based on rigorous user testing. Next, it enables a more cost effective VR use case as it now offers improved compatibility with mid-priced Microsoft Mixed Reality Headsets. Together these improvements are expected to facilitate greater adoption of VR-enabled SCENE as a workflow efficiency tool across the AEC industry.

"The improvements in SCENE 2018 and derived benefits for FARO long range scanners offer another significant contribution to enhancing quality and efficiency across the entire construction life cycle," stated Andreas Gerster, Vice President – Global Construction BIM. "This is the next step to realize our vision of Traceable Construction™ by better capturing and processing reality in 3D and then by sharing information through seamless, tightly integrated best-in-class solutions."

The new FARO Laser-HDR (patent pending) feature in SCENE 2018 improves on conventional multi-exposure HDR techniques by intelligently combining a laser scan image and a photograph through a proprietary FARO process.

FARO is the world's most trusted source for 3D measurement, imaging and realization technology. The Company develops and markets computer-aided measurement and imaging devices and software for Factory Metrology, Construction BIM, Public Safety Forensics, Product Design and 3D Machine.



LiDAR-derived bare-earth model of Mount Katahdin, Maine.

Quantum Spatial Supports Multiple Lidar Data Acquisition Projects for USGS 3D Elevation Program

Public and Private-Sector Coalitions Awarded 3DEP Funds through Annual Broad Agency Announcement (BAA), Which Opened August 31

St. Petersburg, Florida – August 21, 2018 – Quantum Spatial, Inc. (QSI), the nation's largest independent geospatial data firm, announced that it is currently working on more than two dozen Lidar collection projects designed to address the country's need for high-quality topographic data in support of the U.S. Geological Survey (USGS) 3D Elevation Program (3DEP) program. 3DEP, which provides matching federal funds for large-area Lidar collections that benefit multi-agency groups with common geospatial needs, opened its application process on August 31, 2018, with a Broad Agency Announcement (BAA) for fiscal year 2019. Proposals will be due by October 26, 2018.

Since inception of the of the 3DEP program, QSI has worked with a diverse range of public agencies and private sector organizations seeking federal assistance to finance Lidar collections. In addition to providing Lidar survey and data analytics services, QSI also has fostered coalition building among disparate groups that have Lidar needs in the same geographic area, and provided guidance and support for project justifications, shared cost models and project specifications.

"QSI has been our trusted partner on 3DEP projects throughout the State of Wisconsin for many years. Together our firms have completed more than 20,000 square miles of Lidar surveys across the State," said Jason Krueger, manager of Aerial Mapping at Ayres Associates. "As we move into the FY2019 project year, we look forward to working closely with them on additional projects that will bring the many benefits of the 3DEP program to participants at the federal and state level."

3DEP Yields Real Community and Business Value

Working on 33 BAA projects since 2015, QSI continues to see how the Lidar data collected delivers value to the agencies, companies and other organizations in the geographic areas surveyed. Recent projects, awarded under the FY2018 BAA, include:

- North Slope Borough, Alaska – On the Arctic coast, this area is home to eight communities, and subject to increasing erosion, flooding and subsidence that has been exacerbated in recent years by melting permafrost and sea ice retreat. QSI worked with North Slope Borough officials to design the project scope and technical specifications and assisted with developing a cost share model. Now, QSI is in the process of collecting data across 458 square miles, which will provide a crucial baseline for monitoring the impact these changes have on infrastructure, as well as support emergency response efforts and assessment of gravel resources for infrastructure projects.
- Wisconsin Land Information Program (WLIP) – WLIP, working in partnership with the counties of Fond Du Lac, Calumet, Waupaca, Green Lake, Clark and Price, is undertaking a survey of 4,791 square miles, including the last four counties in Wisconsin without Lidar coverage. The elevation layer data will be used by the Federal Emergency Management Agency (FEMA) for floodplain delineation projects, as well as by the Environmental Protection Agency and county land conservation

offices for watershed/pollution monitoring. It also will benefit other federal and state agencies, tribal organizations, private businesses and individuals for planning and zoning, land conservation, utilities, roads and economic development activities. QSI is partnering with Ayres Associates to design and complete this latest component of an ongoing multi-year program to complete Lidar coverage throughout Wisconsin. This partnership has expanded dramatically since 2010, resulting in cost savings and better data sets for all participants.

- Crown of Maine - Since 2010, QSI has performed several Lidar projects, including four 3DEP BAA-funded projects covering more than 23,500 square miles throughout Maine. The most recent project is with the Maine GeoLibrary and Maine Office of GIS, for which QSI will acquire Lidar data across 6,691 square miles to complete the GeoLibrary's long-term plan to achieve initial statewide coverage. The project is supported by several partners, including the Baxter State Park; Town of Carrabassett Valley, Maine; Cooperative Forest Research Unit; Maine Bureau of Parks and Lands; Maine Center for Disease Control and Prevention: Maine Department of Transportation; Maine Geological Survey; the Nature Conservancy; Pattern; State of Maine Emergency Management Agency; Sunrise County Economic Council; USGS; USDA's Natural Resources Conservation Service Maine office; and private landowners. The GeoLibrary is leveraging the Lidar data to support widespread public distribution of geospatial information. Data will be used to modernize local government land records, promote innovative uses of public information for economic development and reduce costs.
- Prince of Wales Island, Alaska – In an earlier BAA award, QSI surveyed 2,055 square miles of Prince of Wales in Alaska, through a project for The Nature Conservancy, U.S. Forest Service, Sealaska and Natural Resources Conservation Service. Working on phase two of the project in 2018, with additional partners the Metlakatla Indian Community and Organized Village of Kake, QSI will survey the southeast portion of the island, which is dominated by closed-canopy, coniferous forest and steep slopes. The project will assist ongoing U.S. Forest Service land management programs, measure current and future timber availability, aid in economically critical fish management studies, evaluate transportation infrastructure, detect geologic hazards, and characterize cultural heritage and mining sites. In addition to doing conducting the survey, QSI was instrumental in helping The Nature Conservancy develop the project and a cost share model, organize groups with similar interests to join the project, and draft the BAA proposal.

"The 3DEP program is unique in that it helps federal agencies, as well as state and local governments and private organizations, minimize their costs for collecting valuable geospatial information, while maximizing its impact for a variety of uses – including flood risk management, wildfire management, planning and response, natural resources conservation, coastal and riverine protection, infrastructure management and geologic resource assessment," said Michael Shillenn, vice president at QSI. "QSI is proud of our work helping foster these collaborative partnerships and providing the advanced surveys and data analytics that deliver insights into our country's constantly changing natural and constructed features."

Organizations or agencies interested in learning more about the 3DEP program and how QSI can help, download this information sheet or contact Michael Shillenn at mshillenn@quantumspatial.com or Oriane Taft at otaft@quantumspatial.com.

LiDAR point cloud, colorized with aerial imagery, of farmland in Door County, Wisconsin.

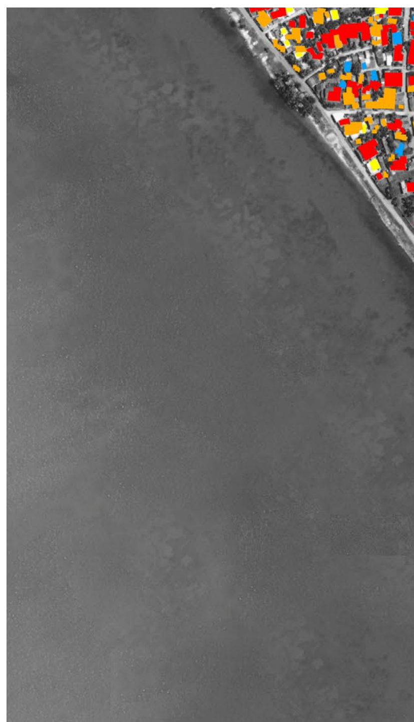
Meaningfu Mappin

When it comes to determining what a particular object is, nothing beats a personal inspection. With a ground survey, one can see the object, and if necessary, photograph it, measure it and record notes about it. For small areas, it's a perfectly viable approach.

But what if the task is to identify and map the entire road network of Dubai over a 30-year period from an office in Colorado? Or from that same office in Colorado, distinguish every building and its roof type across more than 1,200 districts in Sri Lanka? Clearly, personal inspections and data collecting would be cost and time prohibitive.

That is why satellite imagery and advanced spatial analysis technology have been the tools of choice for users who require the vision and intelligence to analyze and map features from remote locations. The difference today, however, is those same tools—particularly the image analysis technology—are more detailed and more intelligent, making them more powerful "explainers."

"With very high-resolution satellite imagery, ancillary data and object-based image analysis software (OBIA), I can identify all the buildings across 20 different regions in Sri Lanka, and I can tell you each building's unique roof material while sitting in my office,"



BY MARY JO **WAGNER**

An eCognition classification of roof types in Puttalam, a northern region in Sri Lanka.

Modern Dubai is synonymous with skyscrapers, high-rise buildings and audacious engineering projects. In the last three decades, its road network increased by 277 percent.

says Chris Lowe, director of imagery analysis with Land Info Worldwide Mapping, an aerial and satellite data provider based in Colorado. "As those roof types directly correlate to poverty levels, economists then have a valuable space-based metric for mapping poverty across the country."

Indeed, taking the well-established satellite-based mapping approach and injecting it with the intelligence of OBIA technology is now providing researchers with the opportunity to take feature classifications like those in Sri Lanka or Dubai and quantify them into more meaningful assessments of changes at a local level.

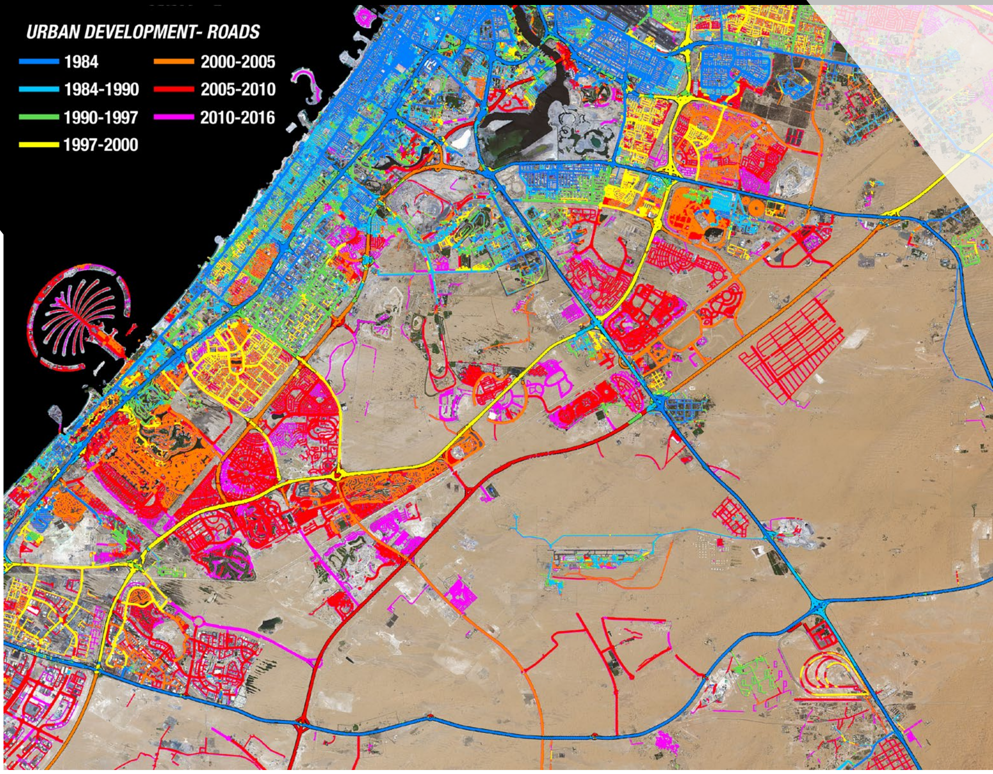
Dubai's Drive

The largest and most populous city in the United Arab Emirates, Dubai is now synonymous with skyscrapers, high-rise buildings—the Burj Khalifa is the world's tallest building—and audacious engineering projects such as the Palm Jumeirah, the world's largest artificial island. In less than 80 years, Dubai has exploded from an impoverished fishing village into a business and tourist mecca with a population of nearly 3 million.

Dubai's most significant boom, however, has been in the last three decades, since the now-popular city initially got electricity and paved its first road in 1961. There were 30 cars in Dubai that transited that first, narrow, 11-km-long road; today that same road is four lanes and there are more than 1.4 million cars in the city.

As part of its Urban Expeditions initiative, a multi-year project spotlighting cities' sustainable solutions for managing urban growth, the National Geographic Society (NGS) wanted to study Dubai's road development over time as an indicator of its expansion. Focusing on five-year intervals between 1984 and 2016, the NGS commissioned Land Info to classify and map Dubai's road development and expansion over that 32-year period.

Although change detection studies are quite common for showing cities'



growth, the NGS project differed, in that, investigating the specific relationship between road networks and urban expansion is uncommon.

"Road networks and how they have changed can enhance the story of a region's growth," says Lowe. "Tightly packed roads may mean a significant influx of residential construction. Roads may have changed from one type to another or disappeared because of certain developments. Integrating roads with other metrics can help bring more meaning to expansion."

Roadwork

Given the nearly 40-year archive of Landsat optical satellite imagery, Lowe chose a series of 26 scenes from three satellites (Landsat 5, 7 and 8) to cover the 6,475 square km (2,500 sq mile) area of interest (AOI). He also acquired road data from OpenStreetMap (OSM), a global, crowd-sourced vector data collection.

To classify the data he used Trimble's eCognition® software, an OBIA technology that employs user-defined processing workflows called rule sets, which automatically detect and classify specified objects and map them.

Because the three Landsat satellites carry different sensors with different spatial resolutions, Lowe had to create slightly varied rule sets to accommodate the different information detail provided in the satellite bands. He also had to process each year individually.

After spending one day customizing the eCognition rule set, Lowe ran the first classification on the two Landsat scenes from 1984. Using a combination of common indices like Normalized Difference Vegetation (NDVI) and Normalized Difference Water (NDWI), along with proprietary spectral- and texture-based indices, he developed a rule set to distinguish objects into four land-cover classes: urban, barren, vegetation and hydrology. With that first sorting complete, he integrated the OSM layer into eCognition and instructed the software to identify just the roads in the urban areas and map those—a two-tier classification process that took only 30 minutes to classify the entire AOI.

Lowe could then apply that master rule set—with slight modifications—to the remaining six classifications, and use each classified year as input for the next year's classification. Using a cumulative classification approach, eCognition produced all seven classifications in about 3.5 hours.

"One of the powers of OBIA is its ability to take in any spatial-based data and classify whatever you tell it to," says Lowe. "So I could integrate the OSM data into it with very little tweaking and I could use the previous year's urban and road classes as inputs for the next year. Combining each year's results as

inputs for the next year enabled eCognition to build on those and classify only the objects that hadn't already been done. It's smarter and more efficient. I couldn't do that with pixel-based image processing software."

The final results showed that Dubai's road network grew from 4,692 km in 1984 (2,915 miles) to 13,000 km (8,077 miles) in 2016, an increase of 277 percent in 32 years. Lowe sent the classified road vectors, by year, the classified urban polygons, by year, and a mosaic of the Landsat imagery for each year to the NGS.

"With this information, the NGS can incorporate the city's road expansion into their other metrics and develop a deeper understanding of Dubai's urban growth in the last three decades."

From Roads to Roofs

Similar to how Dubai's road development can inform the story of its growth, World Bank economists in Sri Lanka are analyzing how building roof materials can help inform the story of the country's economic health.

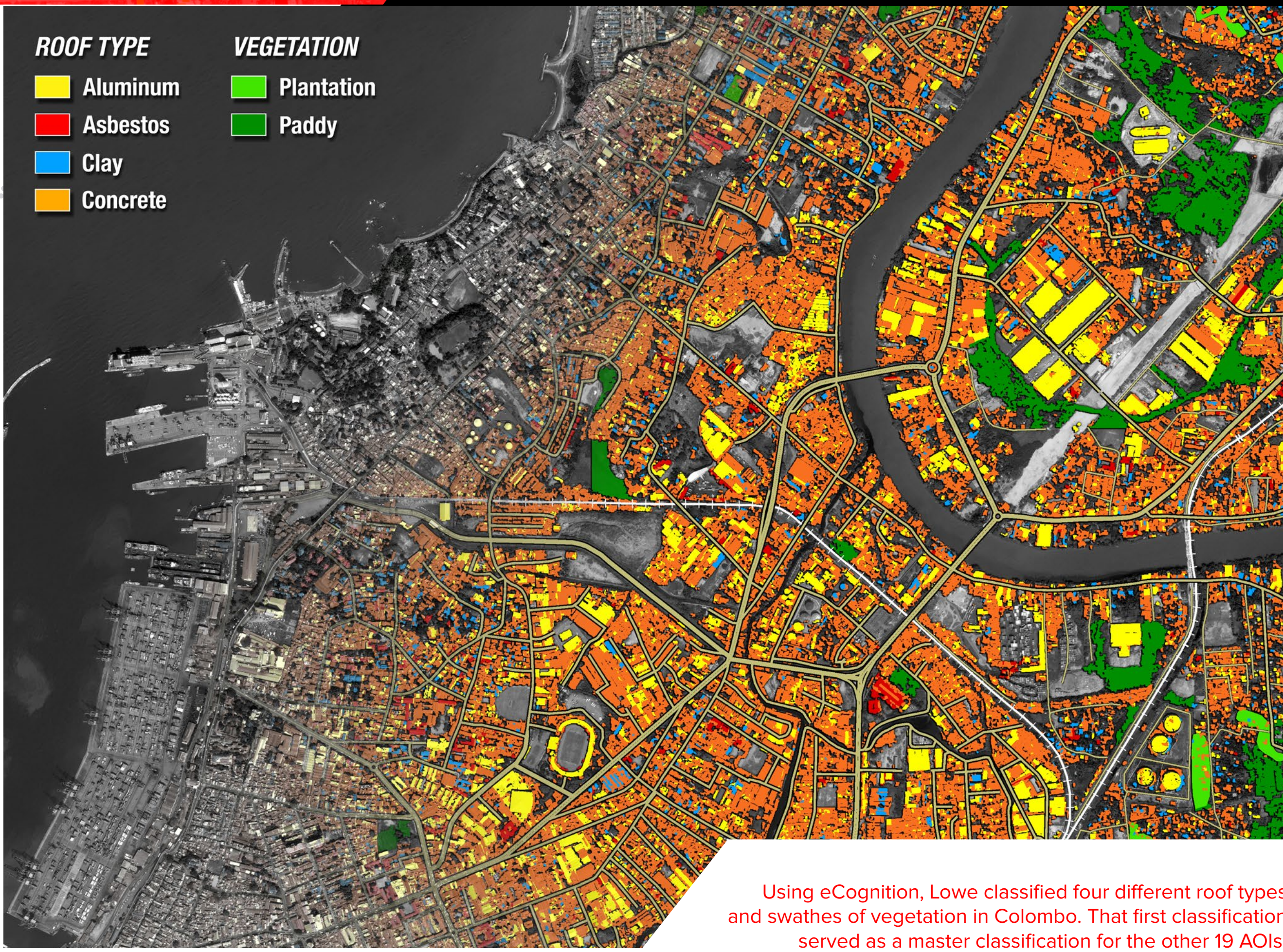
With a population of about 22 million people, the tropical island of Sri Lanka has emerged from its nearly 30-year civil war to become one of the fastest growing economies of the world. And its record of poverty reduction is encouraging—the poverty headcount rate fell from about 22.7 percent in 2002 to 6.1 percent in 2012/13 (excluding the northern and eastern provinces). However, living standards remain low and around 40 percent of the population subsists on less than $2.75 per capita, per day (based on 2005 figures).

Traditionally, the Sri Lankan government has measured its economic well-being through census surveys and detailed, door-to-door Household Income and Expenditure Surveys (HIES). However, census data is only collected once every 10 years and the HIES are collected infrequently, they're incredibly time consuming and they're typically too small to produce reliable estimates below the district level. In addition, some areas of Sri Lanka have been too unsafe to collect survey data.

Given the World Bank's goal to end extreme poverty by 2030, it has been fielding technological solutions to help it more efficiently and effectively compile accurate poverty profiles as a measure of how well aid programs are faring. In June 2015, it launched a project to test the viability of mapping and estimating Sri Lanka's current economic health on a small scale using high-resolution satellite imagery, machine learning and OBIA technology. Although the project

A mix of modern houses and low-income houses line a river in Colombo, the capital city of Sri Lanka, one of the 20 AOIs in the World Bank's "poverty from space" study.

Sarah Antos, World Bank.



Using eCognition, Lowe classified four different roof types and swathes of vegetation in Colombo. That first classification served as a master classification for the other 19 AOIs.

focused on distinguishing seven spatial categories, the World Bank tasked Land Info to identify and classify buildings, roof-type materials and agriculture. The results would be matched to household estimates of per capita consumption based on the country's 2011 census.

"The roof-top materials in Sri Lanka are variable enough that they can be distinguished using high-resolution satellite imagery and OBIA technology and, most importantly, provide economic intelligence," says Nick Hubing, Land Info's President. "Unlike most projects that focus on the 'pixels,' this project was unique in that the World Bank wanted the statistics and real-world analytics based on the classifications."

More Than Just X

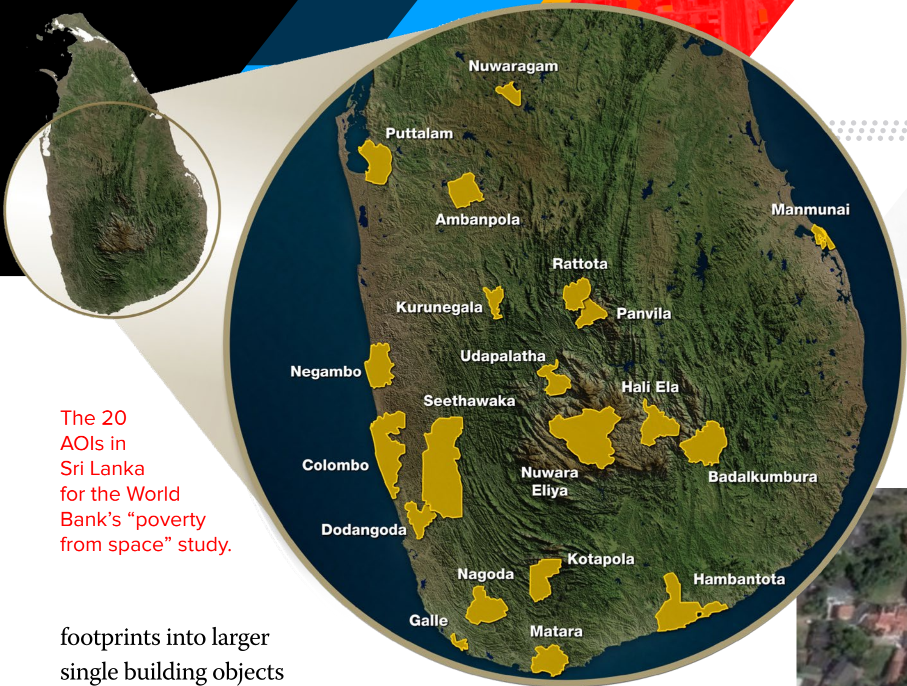
Concentrating predominantly in the south of the country, the World Bank chose 20 AOIs that together created a sample area of approximately 3,500 sq km (1,350 sq mi). The project team acquired 55 individual satellite scenes, acquired between 2010 and 2012, from a combination of Worldview 2, GeoEye 1, and Quickbird 2. These satellites' sensors offer ground sampling distance resolutions that range from 40 cm to 60 cm. Prior to starting the imagery analysis, the imagery was pan-sharpened and orthorectified.

Lowe first created multiple indices to highlight and differentiate ground features found in satellite imagery as well as specialized ones designed to highlight and define buildings in eCognition.

Lowe then needed "training data" to teach eCognition how to isolate roof tops by type. Using Google Earth, he chose some sample sites in the capital city, Colombo, recorded their X,Y coordinates and sent the KML files to the local project team members in Sri Lanka. They conducted ground truthing of those locations, photographing roofs, noting their construction material and how they correlate to wealth. Lowe could convert those point locations and attribute data into Shapefiles and import them directly into eCognition as a thematic feature layer and fuse it with the information derived from the imagery.

Given the complexity and the precision needed for the classification—it required three levels and 44 separate processes—it took Lowe about two weeks to develop the varied rule sets.

Starting with a small area in the Colombo region, he first developed a rule set to separate vegetation from non-vegetation and extract out building footprints using a combination of standard, proprietary and customized spectral and object algorithms. In the second round, he merged the building



The 20 AOIs in Sri Lanka for the World Bank's "poverty from space" study.

footprints into larger single building objects and refined the vegetation areas. Using the first two classifications, he then imported the training samples from the World Bank and ran a third classification to identify and sort each building's roof-type material into four classes: concrete, clay tiles, aluminum and asbestos. Similar to Dubai, Lowe could then use that Colombo dataset as a master classification to apply to the other 19 AOIs.

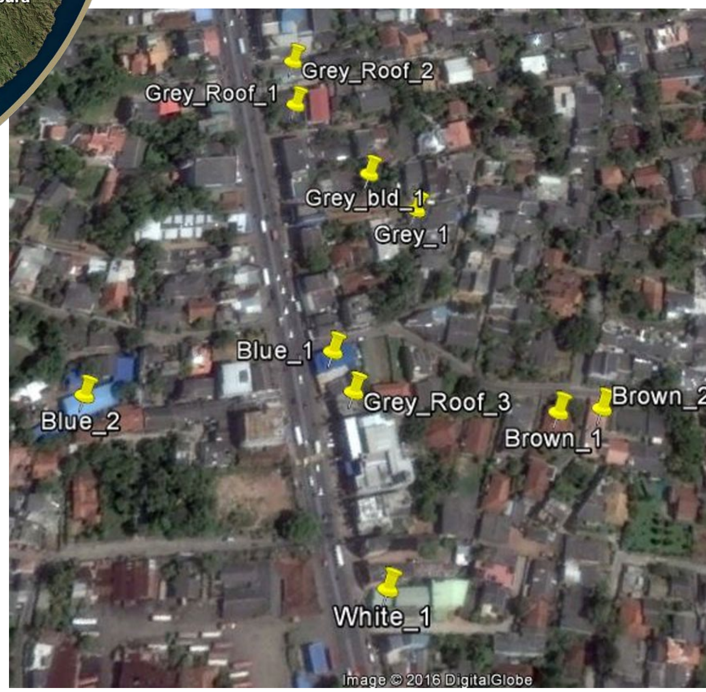
"During this process, the intelligence of the OBIA software actually surprised me," says Lowe. "At first I only had about 12 point samples for Colombo, which wasn't nearly enough to classify that area or any of the others. But, by taking spectral signature samples of the roof materials we knew were definitely aluminum, asbestos or clay and matching them to other training areas inside the Colombo AOI, eCognition automatically identified hundreds of feature objects with those same materials, which I could then apply to the other classifications. It basically trained itself, which I didn't know it would do."

After performing 20 separate classifications, eCognition had extracted and mapped a combination of 1.1 million buildings and building blocks, 42 percent of which have concrete tile roofs, 34 percent have clay, 16 percent have aluminum and 8 percent have asbestos. And according to the World Bank project team, the classification accuracy of the roof types was 90 percent.

"The software is so good at extracting out specific features and with more intelligence—it doesn't just tell you X is a building, it tells you X is a building and it has X-type roof material," says Lowe. "Also, the ability to create one rule set and, with small modifications, apply it to another area, enabled me to be much more efficient and cost-effective."

Based on the project results, the World Bank concluded that roof types can strongly correlate with welfare. Recognizing the methodology as a valuable supplement to household survey data and as a more efficient, safe and labor-saving process, economists are considering applying the system to generate more frequent poverty maps.

Lowe used Google Earth to chose sample roof types of Colombo as eCognition training data. Sri Lankan project team members verified those roof types with ground surveys.



Indeed, from roads to roofs, the combination of the heightened data detail of remote sensing and the smartness of OBIA technology is proving to be a viable qualifier for those wanting to know not only what a particular object is, but how it relates to an area's overall story. And that's a story worth reading.

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Autonomous Vehicles Operational Thanks to Lidar

May Mobility relies on home-grown sensor fusion to guide vehicles on fixed route

Side views of May Shuttle, showing long rear door and side sensor suite

When Managing Editor Stewart Walker visited Cepton Technologies to investigate their efforts to build on their automotive lidar experience with a sensor designed for UAVs[1], Cepton recommended that he visit its customer, May Mobility, which was successfully using its sensors on autonomous vehicles for transporting office workers in Detroit, Michigan. He visited May Mobility's headquarters in Ann Arbor, Michigan and its operations center in Detroit in July 2018. Here is what he discovered.

Ann Arbor headquarters

The purpose of my visit was to interview May Mobility's CTO, Dr. Steve Vozar. When I arrived at their Ann Arbor office, all the principals were in Detroit, submerged in preparation for a visit by investors—a state of affairs not so different from Silicon Valley! I hit gold, therefore, when the interview was postponed till three days later in Detroit and instead I was hosted in Ann Arbor by Head of Product Zafar Razzacki, who gave me a tour of the production area, accompanied by insightful commentary. Like many May Mobility employees, Zafar is a graduate of the University of Michigan (U-M). He came to May Mobility by way of Google and General Motors. He said that the company is expanding rapidly—the software development "bullpen" area where we started the tour had seen a doubling of its population in a few weeks.

BY DR. A. STEWART **WALKER**

[1] Walker, A.S., 2018. Cepton Technologies: the Silicon Valley approach to lidar sensor development, *LIDAR Magazine,* 8(2): 34-44, March/April.

Charging and data download facility in May Mobility's Detroit operations center, showing the specially installed electrical and data cables and connections; in left-hand image, left-hand Cepton HR80W can be seen in each of the nearest two vehicles; in right-hand image, roof-mounted Velodyne VLP-16 Puck Hi-Res units can be seen on all three vehicles

He agreed with me that automotive lidar will influence the development of airborne owing to the enormously larger market size. He thinks we will see a convergence of these technologies. They will inform each other, resulting in a convergence of different applications, and learn from each other. The software developers and robotics engineers in the bullpen work in the areas of autonomy, perception and control software. They include U-M alumni and experienced personnel from the industry, e.g. Bosch and Argo. May Mobility's vehicles provide a service to transport employees of Quicken Loans and Bedrock in downtown Detroit. So far, Bedrock is happy with May Mobility's performance and excited about the future. The company shares its name, of course, with the home of the Flintstones. The state of Michigan licenses May Mobility to drive autonomously and the city of Detroit has given its permission to mount infrastructure on light posts along the route. Zafar emphasized the complementary purposes of the units in their sensor suite, to give a fuller picture of the world.

As we moved through the employees' break area, I noticed a touch of the idiosyncracy one often finds in start-ups—a four-seater electric vehicle, in use as a conference room for small meetings. We proceeded into the space where vehicle engineering happens, packed with machining equipment—May Mobility has the capability to create prototype molds for some of the vehicle parts. These are sent to manufacturing partners, e.g. plastics suppliers. I saw the custom-made housing for side-mounted sensors and a cowl for the sensors in the front housing, which includes two Cepton HR80Ws. This shop is where they do fabrication work, electrical assembly, and prototyping.

Is there a human driver? A fleet attendant sits behind a custom-built "T-bar", which he can grab if necessary, but for the most part the vehicles are autonomous and learn as they go. The attendant conforms with safety requirements and makes passengers more comfortable, building trust, i.e. users take a comfortable step from a human-driven bus or taxi. The vehicle

Front view of May Shuttle, showing front sensor suite; the two Cepton HR80Ws are in the top row

is a six-seater, so there are five seats for passengers. It's pleasant to the eye, inside and out. Zafar confirmed, "People stop them on the road and say it's cute." We went to the rear of the vehicle. The battery packs are massive, to give a four-hour service model. The vehicle has surprisingly heavy construction, appearing to be rigid and stable. It's not a big industrial, diesel bus, yet it's a proper full-sized vehicle, not a glorified golf-cart or science experiment. The spaciousness surprises people.

Before leaving, I asked Zafar about May Mobility's ambitions regarding small vehicles for use in warehouses. They are, "Actively exploring what our vehicle portfolio should look like". They have lots of flexibility for different application types and anticipate demand for larger form-factors. He was sure that there is immense potential for more business and making all aspects of the experience better—sensors, software, vehicle.

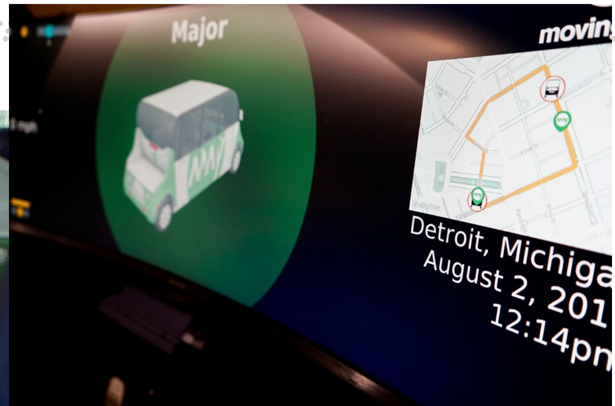
Detroit operations center

On arrival at the Detroit office, I was welcomed by co-founder and CEO, Edwin Olson, who has three degrees from MIT and is a part-time faculty member at U-M, where his main responsibility is to run the APRIL Robotics Laboratory (Autonomy, Perception, Robotics, Interfaces, and Learning; May Mobility was named after the month that follows April). Co-founder and COO Alisyn Malek was also there, but my interview was with co-founder and CTO Steve Vozar. Edwin was on Steve's PhD committee at U-M. Indeed, Steve and Alisyn were undergraduates at U-M at the same time but didn't know each other. The Detroit office is an operations center, a sort of "mission control" with staff looking at the route on a big wall-screen with detailed mapping, moving icons etc. There are four smaller screens providing additional information.

Steve agreed with Zafar that automotive lidar will benefit the airborne side, eventually bringing prices down, but there will be competition for sensors, so it may be hard for manufacturers to prioritize features for airborne use—smaller buyers may get lost in the fray.

How and when did the company begin? Ed, Alisyn and Steve, with background in "big auto", such as Ford, General Motors and Toyota, and academic life, were looking at the 10-15-20-year roadmap for AVs. They mused on whether there was a better way: was there anything useful that could be done in the meantime before self-owned, fully autonomous passenger cars were ready for prime time? To reduce risk to acceptable levels, they decided to "slice and dice today's technology to serve certain markets," such as "community-scale fleet transportation." These markets embraced requirements such as lower speeds and complex environments, but sensors were available that could see far enough; furthermore, stopping distances were shorter at lower speeds. They felt that freeway operation of AVs was hampered by sensor performance but designing for speeds of 20-25 mph was feasible, so they could "get customers in car, turn sensors on, be ready for 'aha moments.'" Top speed doesn't matter on short routes. The maximum speed on the Detroit route is 25 mph, with most operations at 15-18 mph, which feels normal in a dense urban setting. Steve emphasized that May Mobility aspires not to fundamental research but to take applications to the next level as available technologies improve.

The documents forming May Mobility were signed in January 2017, funding was sourced in late spring and the new company moved into its Ann Arbor offices in May. We talked about Cepton's new offices and Steve had been there on their first day while Cepton was moving in. May Mobility has expanded rapidly and now has almost 60 employees, more than 40 full-time and the remainder, contractors. The Detroit office officially opened with a media/VIP "ride along" on 26 June 2018 and went operational the next day, though they had been preparing for months. They don't do development in Detroit—it's purely a site operations center. Staff can see the infrastructure of



Views of 49-inch LED display

the environment they run in, the status of roadside sensing units (RSUs), locations of vehicles and so on.

Is May Mobility a spinoff from U-M? Many staff, including core and original employees, came from U-M. The company licensed some technology from U-M in exchange for equity. U-M has been very supportive: May Mobility has an excellent relationship with the university and uses its Mcity Test Facility, built jointly with Michigan Department of Transportation, the first purpose-built proving ground for testing connected and automated vehicles and technologies in simulated urban and suburban driving environments. The local ecosystem is very advantageous. There are other start-ups, e.g Duo Security is the first unicorn, and strong support organizations such as Ann Arbor Spark, Michigan Economic Development Corporation and Planet M. He added that U-M is a great talent pipeline—May Mobility is still hiring college graduates.

How did May Mobility land Bedrock as its first customer? Business development is part of Alisyn's brief. After an introduction by one of May Mobility's investors, Detroit Venture Partners, Alisyn contacted Bedrock's VP Parking and Mobility. Bedrock is the real estate management arm of Dan Gilbert's Rock Ventures empire, with hundreds of properties including parking garages. It offers an amenity, connecting people working for its tenants with transportation to parking garages. May Mobility's contract is for moving people, mainly employees of Quicken Loans, a mortgage lender, from Detroit's Bricktown parking garage to Cadillac Square, a clockwise circuit over a mile-long. This process illustrates the value of investors helping out with connections, not just funding.

I asked Steve about the Society of Automotive Engineers' five levels of autonomous vehicles. May Mobility's solution is classified as level 4, which means no human interaction, though it is permitted in exceptional circumstances, but May Mobility is full autonomy in pre-mapped, geofenced areas.

The vehicle

The vehicle platform is a Polaris GEM e6 electric six-seater. May Mobility buys stock GEMs and performs a deep-dive integration, including the configuration of the seating and doors, sensor suite, compute stack, vehicle control unit, drive-by-wire system, custom sensor cowls, custom user interface and custom glass roof, slightly tinted to protect against intense sunlight, which creates a pleasant user experience, especially in Detroit with its beautiful large buildings. I sat in a May Shuttle, as the final product is called, and was attracted by the beautiful 49-inch curved monitor serving as a dashboard. I observed the custom T-bar for fleet attendants to supervise the vehicle. The middle row of seats is flipped around, so that they are rear-facing, like a London taxi. The standard e6 has three doors on each side, of which two are replaced by one long one, making it very easy to get in and out. This configuration is based on feedback from the pilot in Detroit.

In the trunk there is a bay of huge lithium-ion batteries, for which there are charging stations in the operations center—each vehicle comes in for recharge at the end of its shift and May Mobility manages this as part of the service. Five vehicles are deployed for each shift, typically three for the morning and evening peaks, two at other times. Thus May Mobility is not just a software company, but has a sense of design, deploys a team designated to the platform, and can use sensors fast and in an integrated way. "Passengers must trust to get in with family, grandma too."

I asked about one of May Mobility's suppliers, Magna International, which is a massive automotive supplier with 172,000 employees, yet not known to me—"sneaky big" in Steve's words. Magna is May Mobility's up-fitter or manufacturer. May Mobility designs and does the engineering and prototyping of the vehicle in Ann Arbor, then Magna produces it at scale. This is where the molds that I had seen come into play.

How did the relationship with Cepton begin? May Mobility has known Cepton's senior director, business development, Wei Wei, for a long time. Steve's team saw demos of the HR80W and knew the technology was special. The two companies share similar values in terms of getting product into customers' hands fast. May Mobility was impressed with Cepton's quick reactions to feedback and the result was a strong working relationship. Steve was blunt: Cepton provided "the best customer service I've ever encountered. They're doing a great job." They received their first unit from Cepton in the summer of 2017 on affordable terms. The HR80W point cloud immediately captured the engineers' imaginations, since its point density is much higher than those from lidars with rotating mirrors or prisms—Steve described it as very similar to cross-hatching with vertical lines, so it complements the beam pattern of the spinning lidar, as well as offering satisfactory range, accuracy and precision. No beams are wasted. The two HR80Ws have 60° degree FOV and are mounted at 45° to each other, so they are performing the long-range sensing in the entire direction of travel, including stop signs, cross traffic etc. May Mobility is excited about Cepton's new Vista sensor and the companies are working together to integrate it in the vehicle. The mounting and electronics are similar to those required by the HR80W, but the Vista offers higher performance and is half the size of the HR80W.

> "Passengers must trust to get in with family, grandma too."

Indeed, there is a gallimaufry of sensors on the vehicle, giving redundancy round the full 360°: in addition to the Cepton sensors at the front, there is a Velodyne VLP-16 Puck Hi-Res on the roof, and multiple imaging, flash lidar and radar sensors on all four sides. May Mobility prefers not to reveal the total number of sensors on the vehicle, but it must be 25 or more. The measurements are transformed not into point clouds, but information covering an area in front of the sensors, to know whether there is something there, rather like a multi-beam rangefinder. Part of May Mobility's sensor strategy embraces different modalities of sensing, with orthogonal strengths and weaknesses. Steve explained that the Puck on the roof is part of a typical AV configuration and helps with localization as well as object detection.

We turned to the other sensors, starting with the GNSS/IMU. May Mobility deploys a fiber optic gyro but does not use integrated GNSS/IMU, preferring to separate out all components. The gyro is sourced from KVH Industries. There is a GNSS receiver, but May Mobility does not rely on it for localization: "lidar is our heavy hitter for localization. We don't rely on GPS for localization, but instead we rely on the sensors on the vehicle ... we use lidar, radar, cameras."

The RSUs are special to May Mobility and are feasible for deployments at a community scale. May Mobility uses RSUs as additional sensors—redundancy and sensor fusion are two of their core competencies. Also, RSUs are a different way of sensing the surroundings, because they are not on the vehicle itself—they provide "eyes on the road" when the vehicle isn't there.

The hardware is impressive, but making it all work is even more so. May Mobility's approach to sensor fusion and autonomy is key: the "secret sauce" is its MayStack software, which is extensively reported in the academic literature[2]. As part of the MayStack, a key algorithm for planning vehicle behavior is called Multi-Policy Decision-Making (MPDM). Developed at the APRIL lab and licensed through the U-M Technology Transfer program, MPDM is the real differentiator for building May Mobility's intelligent system. It gives a 360-degree view of objects on and around the road, along routes where the team has created detailed maps of lane edges, traffic signals, road signage

[2] There are numerous papers in peer-reviewed journals co-authored by Ed or Steve, for example: Mehta, D., G. Ferrer and E. Olson, 2016. Autonomous navigation in dynamic social environments using Multi-Policy Decision Making, *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 1190-1197.

and speed limits, and taken into account pedestrian, cyclist and auto traffic. By using a robust suite of on-vehicle and environmental sensors and powerful software, the vehicle is able to traverse complex urban scenarios on its own, without human intervention. The current approach to building autonomous systems relies on training with known scenarios, including edge cases which are difficult to define and collect. With MPDM, May Mobility's systems are able to model and predict future behaviors of agents in any scenario because it understands the situation instead of having to recognize it and recall a specific coded solution.

I was curious because the product that May Mobility provides to Bedrock is a shuttle service, so have they had to write more software for calling the shuttle, optimizing timing to minimize dwell time and so on? Steve described the current offering as a "fixed route circulator" and emphasized that May Mobility is committed to adding features as customers demand. In order to go to market and start the revenue stream, May Mobility could not implement everything, but began with a really solid vehicle and didn't make assumptions about all customer requirements in advance. The team developed software "from the ground up", but also had to design a shuttle service. They had to spin up the Detroit operations center, simultaneously adding a team of staff and technicians—this is part of the product. They like to hire people in the local communities where they operate, making the company "sticky", with a physical location for interested people to come to talk. I wondered, therefore, whether May Mobility's solution, which relies heavily on using local companies and setting up a control center, will scale. Steve admitted that any time they go into a new location, they require a physical presence. Vehicles have to be charged and able to offload data, but that's a way of getting a foothold in the community.

I gave Steve the example of San Diego airport, where large buses are driven along a special road just inside the airfield perimeter, to and from the car rental facility, while roads surrounding Lindbergh Field are cluttered with minibuses serving parking lots and hotels. Zafar had said that if May Mobility can build business models to cope with those flows, it can reduce passenger dwell time waiting for a vehicle. He thought that this could be tackled, but May Mobility has larger aspirations, both shuttle-type applications and a more robust service model to replace all vehicles in a particular urban setting, point-to-point on demand like Uber. The route in Detroit serves a real need, replacing a 30-person diesel shuttle bus with two or three AVs, giving the same throughput with lower latency, i.e. better service. I pointed out, in the airport context, that the vehicle has little or no space for luggage (the trunk is full of batteries) and Steve agreed that this is a challenge to come. I suggested twin vehicles, the second one carrying luggage for the passengers in the first, so Steve gracefully said he would consider this!

May Mobility's current focus though is smooth running in Detroit and several more customers are currently being engaged. Cities are a compelling target market, but there are great advantages to working on a private campus. They want to cover a wide spectrum of different markets. What are May Mobility's plans for the future? The first target market is enterprise and municipal customers in more cities across the US. The company has strong sales and customer success teams engaged on the quest to add more customers.

I asked whether there are any other sensors May Mobility would like, for example, for weather. Steve was confident that the current sensor suite can meet Detroit's challenging weather, but he and the team stay on the look-out for new sensors with novel physics or fresh applications. They are always evaluating new types of sensor and like to try things out.

We walked to the parking garage of the operations center and saw "where the vehicles sleep at night." The bays had special electrical wiring for charging and fiber optic cable for data download, so that's another part of the investment. The vehicle downloads everything acquired since the last download, from the solid-state drive on board to the company's own servers. The database is then updated. It's how the system learns what the vehicles are seeing and enables new ideas to be validated. All the mapping is their own, albeit in a small area. They map only what they need—it's part of their pragmatic approach. The ideal site for May Mobility is less than ten square miles with routes of one to three miles within a clearly defined, geofenced area.

The fleet attendant builds customer trust and gives peace of mind—Steve drew the analogy of early elevators. He firmly believes May Mobility will get there, just like elevators!

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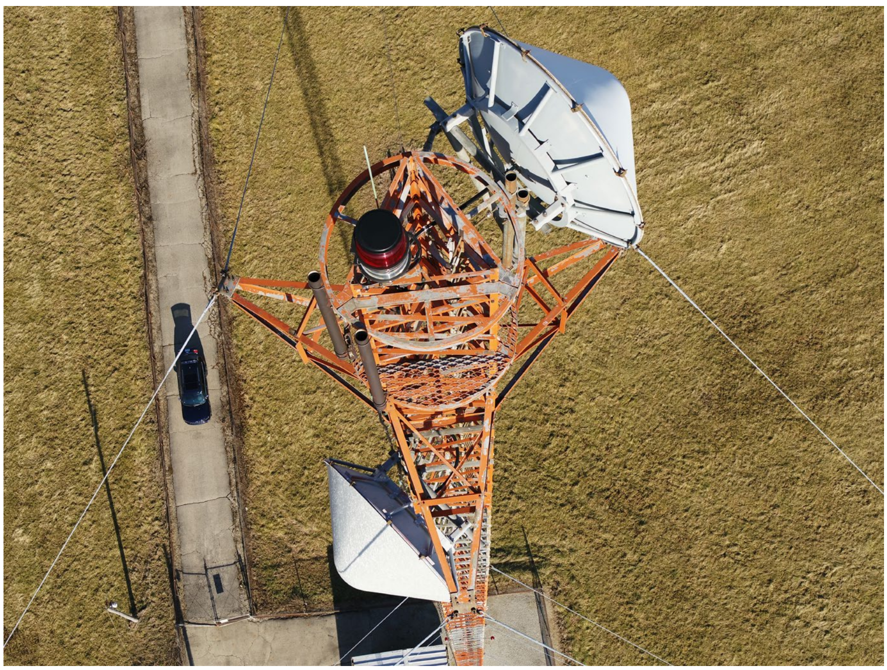
UAS Data Becomes Increasingly Valuable for Worksite Monitoring

Commercial Role of UAS Expands

In 2013, the Association for Unmanned Vehicle Systems International (AUVSI) predicted that from 2015-2025 the integration of unmanned aircraft systems (UAS) into the National Airspace System would pump more than $82 billion into the U.S. economy, and create more than 100,000 jobs in the first three years. Since that study, continually emerging technologies for these compact, highly accurate and easily portable mapping tools have made those once-hyperbolic numbers seem downright conservative.

Today, the spectrum of commercial UAS applications is broad, ranging from product delivery and media coverage to precision mapping and worksite monitoring. For mapping and worksites specifically, UAS has proven invaluable because it can efficiently collect high-resolution, detailed oblique perspectives that cannot be provided by conventional land or other ground-based surveying tools within a small site.

The tool is ideal to monitor the status of construction progress or agriculture yield, explore and document remote or hazardous sites, provide accurate information in support of asset management systems, and verify safety issues and concerns at any location. These uses offer extensive value for multiple applications, providing visualization and verification tools for all involved parties from the start of a project to its completion.



Woolpert uses high-resolution imagery to inspect infrastructure of all sorts, such as this communications tower.

Courtesy of Woolpert

BY AARON LAWRENCE

UAS Applications: Assets for Asset Management

UAS has quickly become an asset to the commercial construction landscape because it provides fast, detailed and unlimited monitoring. A UAS camera

NEW
ScanLook TreX
Trimble
LiDAR USA
SNOOPY SERIES
Go Far
256-274-1616
LiDAR USA
Fagerman Technologies Inc.
sales@lidarusa.com
NEW
SNOOPY
SERIES
RIEGL inside
LiDAR USA
NEW
myPointClouds.com
powered by LiDARUSA
-Upload your LAS or LAZ
-Supports any vendor
-First month free
-Share with anybody, maintain control, restrict access
-Take measurements
-Scalable Solutions
-Works with any PointCloud (LiDAR or image derived)

Woolpert used an unmanned aircraft system (UAS) to collect this colorized point cloud of a utility substation. Woolpert has used UAS in more than 100 projects since 2014 to collect data, monitor construction, verify safety issues, explore remote and tight locations and support airport asset management programs.

Courtesy of Woolpert

that can see down to a quarter of a centimeter from 30 meters away can provide thousands of images from nearly any perspective to document the construction process. As technology improves, it will be possible to see detail as fine as the braids on a copper wire.

This increasingly close inspection allows stakeholders to check whether materials meet the specifications of the project or if a lesser quality material was substituted. By collecting numerous datasets and providing those point clouds at specific construction benchmarks, UAS allows the client to literally watch their site being built online, making sure a project is proceeding on schedule and that contractors are maintaining a safe site.

The collection tool also eliminates the necessity for project managers to visit a site daily, saving travel time and lost job hours. UAS data can be delivered the day after flying. If any aspect of a project is raising concerns from neighbors or government officials, project managers can verify or dispute those concerns by simply referring to the latest data collected by the UAS, which can be within hours. "Concerned parties can track a project every day from the comfort of their office computer," said Ethan Schreuder, Woolpert UAS pilot and survey technician. "We're able to provide a 3D view of any project using easily accessible online visualization tools. It provides assurance, accountability and transparency throughout the build."

This same process can be applied to multiple other worksites. Savannah/Hilton Head International Airport (SAV) recently began using UAS to support its daily airport and airfield operations. The airport, with integration guidance by Woolpert, has employed this tool to address wildlife management/hazard mitigation and daytime perimeter surveillance, routine needs for an airport that require a high level of safety and efficiency. According to Thomas Mackie, Woolpert vice president and geospatial aviation practice leader, this additional capability with UAS provides an opportunity to minimize frequency and duration of time spent in safety critical areas, while creating valuable geodata as part of the airport's system of records. "Instead of driving up and down a runway to identify pavement or marking issues, the airport can use UAS to collect data remotely and create work orders with accurate coordinates and valuable imagery," Mackie said. SAV is expanding UAS flight operations by using previously performed aeronautical surveys and base mapping as reference information to conduct asset management and change detection tasks. The UAS collects data remotely and provides immediately available and accurate imagery to determine, for example, whether a runway has a defect or burned out lighting.

UAS can also provide three-dimensional geospatial survey data and real-time inventory assessments to collect pre-construction and post-construction images in inaccessible locations, and provide a needed safety element. "Remote sites are the perfect use for this technology," Schreuder said, noting that Woolpert has used UAS in more than 100 projects since 2014. "No one wants to fuel up a plane and fly out to the middle of the desert to collect for a couple of areas. At the same time, UAS is the most effective tool for nearby sites in which other collection methods would prove hazardous."

Another important application of UAS imagery is to identify potential structural and physical dangers before human climbers visually inspect aging aircraft navigation towers at sites across the country. "The UAS identifies structural issues associated with the climb, or if there are animals or insects living inside isolated structures such as these—and do so before a climber is 200 feet above the ground," Schreuder said.

Ethan Schreuder, Woolpert UAS pilot, operates a drone outside Woolpert's headquarters to demonstrate how the UAS can provide a digital record of a construction project.

Photo courtesy of Ty Greenlees, Dayton Daily News)

"They still have to go up there but they know what tower section the bees are in or where the ladder is missing rungs. This allows the climbers to prepare and protect themselves better, and more efficiently complete their assessment."

Safety and cost efficiencies also are components of UAS work at utility substations, allowing imagers to document ongoing conditions as utilities rebuild aging infrastructure or bring in new equipment. Dan Michalec, Woolpert geospatial specialist, said the firm has used UAS imagery and collected 3D lidar scans of multiple utility substations, recreating the geometry of each in a computer-aided drafting environment and providing geospatial data in a 3D colorized point cloud. The data allows each substation to be scanned to address safety concerns and determine the approach for 3D laser scanning and needed survey tasks to meet project requirements.

In one case, a Leica P50 laser scanner was used to capture lidar and imagery data within the fence line, as well as all other features at the location. To identify the equipment, foundations and other site features, technicians classified the colorized point clouds into site-specific categories. The CAD files, 3D models, surfaces and point clouds easily identify buildings, equipment, ground elevations, fence lines, utilities, storm and sewer manholes, foundations, cable trenches and other features in each substation.

"Safely installing new or replacing old equipment often requires a disruption of service to customers, so time is critical. That's why flights are planned strategically around outages," Michalec said. "This way, data acquisition is optimized to support construction scheduling and

Woolpert uses UAS data to monitor construction as well as demolition. Above is a point cloud showing how demolition is progressing at a jobsite.
Courtesy of Woolpert

Ethan Schreuder, Woolpert UAS pilot.
Courtesy of Woolpert

Aaron Lawrence, GISP, Woolpert UAS Technology Manager.
Courtesy of Woolpert

customer impact. By arranging flights around key tasks, UAS data provides a clear picture of site conditions prior to taking equipment offline or energizing site components. As the quality of UAS data increases, end users can utilize the accuracy of terrestrial lidar datasets and the quick responsiveness of UAS datasets to build unparalleled site visualizations."

The benefits realized by utility companies mirror those of construction projects, including access to current digital data, reduction of construction errors, minimized rework in the field, increased safety with fewer construction workers exposed to electricity, decreased travel time and fewer work hours lost.

Expanding Relationship of Lidar and UAS

UAS data is not expected to replace manned aerial lidar collections for large projects, such as mapping entire states or countries, because this would not be economical. However, where large areas have been carpeted with lidar data, integrating UAS-collected data provides a swift and cost-effective way to capture and update smaller areas within the larger dataset coverage. Additionally, the use of UAS for collection of smaller project areas to get a better understanding of the 3D environment at much higher resolution is achievable.

"If an accurate and comprehensive surface is critical, lidar is best," Schreuder said. "If you need to see if a fuse was installed correctly, high-resolution imagery from UAS is ideal. UAS will tell you whether a construction project is on track and provide a digital record, and can verify that information rapidly."

In many cases, existing lidar can assist in flight planning, conducting line-of-sight analysis prior to arriving on site. UAS also can make outdated data useful again. For example, states that have completed lidar mapping of large areas don't have to spend the money to remap after a new subdivision has been completed. UAS can provide the images to insert a patch into the existing data.

Collecting lidar data via UAS for commercial applications has also been

UAS data is being used to monitor the progress of construction on a runway extension, allowing stakeholders from different locations to watch as the project advances.

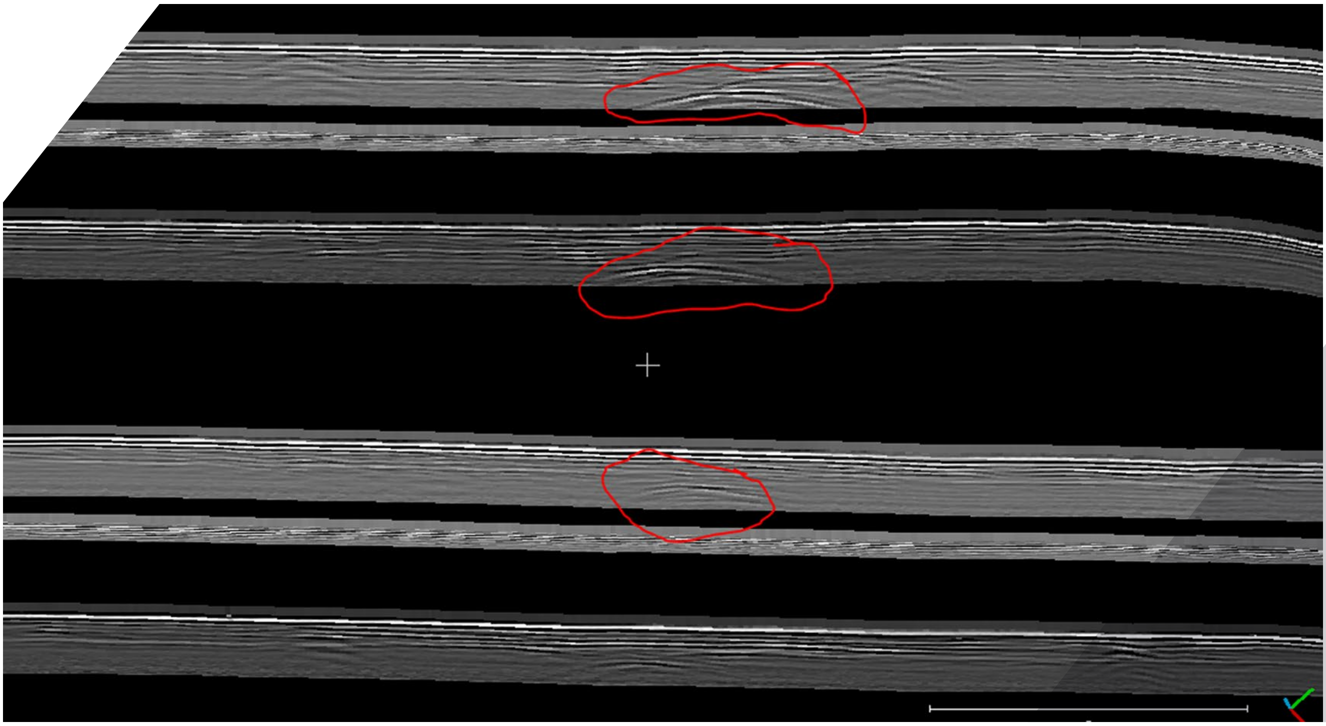
Courtesy of Woolpert

gaining acceptance. While there have been significant advances in miniaturizing lidar, as well as GNSS and inertial measurement unit (IMU) technology, for integration on UAS, there is still discussion and evaluation as to whether an integrated lidar system is capable of producing the highly accurate data products currently being achieved by conventional methods. "The technology will only become more accurate," Schreuder added. "Cameras and UAV lidar will only get better."

The addition of hyperspectral sensors advances the potential for commercial UAS uses beyond 3D. Hyperspectral sensors have been miniaturized to the point where 300 spectral bands can be collected from a sensor the size of a golf ball, enabling specific materials to be identified via their spectral signatures. Applications of hyperspectral imagery in the field of agriculture currently allow seed manufacturers to use UAS data collection to determine which product was the most effective and productive in a field, or to detect weeds or insect or mold issues that limit the yield. The data gathered by UAS helps provide information about the condition of the soil or whether crops need increased irrigation, or assists in remotely planning the most efficient methods to boost crop production levels. U.S. Department of Agriculture and Forest Service officials also could use hyperspectral imaging collected by UAS to ascertain whether an invasive insect, such as the emerald ash borer, has decimated the interior structure of a 100-foot-tall tree. Having and sharing this information can save lives, homes and other infrastructure by addressing the affected trees before Mother Nature crashes the scene.

"The bottom line is that there is literally no limit to the collection and application of UAS and lidar data, whether they are used independently or together," Schreuder said. "Understanding these tools and employing these technologies appropriately allows the most effective, precise collections, which then yield the highest-quality results."

Aaron Lawrence, GISP, is the UAS Technology Manager for Woolpert, an international architecture, engineering and geospatial (AEG) firm. Woolpert was the first surveying and aerial mapping company to be approved by the FAA to fly UAS commercially in designated airspace, and currently has 15 licensed UAS pilots with a variety of AEG backgrounds. Lawrence, who has been with the firm for 15 years, was one of the first in the country to earn a FAA Part 107 UAS pilot license.



Subsurface Utilities Meet Mobile Lidar

BY BRENT GELHAR

There has been a dramatic growth in the past decade in subsurface utility mapping, but the need for improved utility location continues to be an issue. "Plans alone are not sufficient to identify and locate services before starting work. They provide basic information on which to base a thorough site survey before work begins" as stated by UK Health and Safety [1]. The US Common Ground Alliance (CGA) also reported in 2014 some 17% ($136 Billion) of utility related accidents or near misses were attributed to "insufficient locating practices"[2]. The U.S. Occupational Safety & Health Administration (OSHA) also reports that, "The fatality rate for excavation work is 112% higher than the rate for general construction". "When applied properly during the design phase, Subsurface Utility Engineering (SUE) provides significant cost and damage-avoidance benefits and the opportunity to correct inaccuracies in existing facility records." [3] The National Transportation Safety Board (NTSB) and other authorities often cite the lack of location data as a factor in pipeline accidents.[4]

Although great improvement has been implemented in the past decade with the rolling out of "Dig Safe", "One Call", "811" and other similar services, "65% of all buried utilities in the US are privately owned, Dial 811 will not respond to these facilities," according to the CGA Dirt Report. There is also a huge liability of having survey crews venturing onto active roadways to identify and mark utility locations, so keeping staff safe while not impeding traffic flow is becoming more and more of an issue to companies and municipalities. To the subsurface utility

engineering and mapping (SUE/SUM) business community, this is of great importance relating to insurance and human liability.

Taking A New Approach

The DGT Associates Subsurface Utility Mapping group, Boston, MA, USA, led by Michael Twohig, requested a proof-of-concept project for simultaneous roadway speed data collection of mobile lidar, imagery and ground penetrating radar (GPR) with multiple antennas and different frequencies. DGT has been looking for technology partners that have the existing, reliable technologies that could build a mobile mapping system to reduce the time geospatial staff (surveyors and utility locating technicians) are working in active roadways and travel lanes. The primary purpose of this method is to minimize the need for subsurface utility detection to be carried out in live traffic. Every year there are numerous accidents involving vehicles hitting utility locator crews (**Figure 1**). This has caused many authorities to be putting much stricter regulations on survey teams working in roadway environments. The target of this project is to prove a viable workflow for mass data collection and virtual data analysis in a safe office environment minimizing the need to place survey crews on the roadway.

Simultaneous Data Collection

Through a collaboration by SITECO Informatica, Bologna, Italy (SITECO), Sensors and Software Inc, Mississauga, ON, Canada (SSI), and DGT Associates, Boston MA, the project was realized to collect simultaneous lidar data above ground and GPR data below the surface. SITECO manufactures the RoadScanner family of high performance mobile mapping products while SSI is a leader in ground penetrating radar sensors. Additionally, SSI's sister company, RoadMap Inc. also of Mississauga, Canada, has an existing fully integrated trailer system for roadway speed data collection. All that was required was mounting the SITECO RoadScanner-Compact (RS-C) system, equipped with dual Faro Focus 3Dlaser scanners, an Applanix AP20 Inertial Navigation System and FLIR Ladybug 5 spherical camera, the existing trailer, already outfitted for a 3 GPR antenna configuration with 2x 250MHZ antennas on the outsides and a single 1000MHZ antenna in the centre (**Figures 2**, **3** & **4**). Future plans are to additionally integrate thermal and/or multispectral sensors along with road surface planimetric sensors, such as SITECO has recently delivered their PaveScanner system which includes the LCMS profilers from Pavemetrics, Quebec, Canada[5].

Figure 2: SITECO's Roadscanner Compact equipped with with dual FARO Focus scanners mounted on SSI's mobile GPR trailer with three antennae.

Figure 1: The utility workspace has long been a hazardous place.

Figure 3

Figure 4

There were 2 phases to this project, the first carried out on 14 May 2018 was the initial test drive, a short data collect of approximately 15 minutes, covering approx. 4 km, followed by a second more comprehensive data collect on 16 May 2018, comprising 19 km over a 1 hour period over a wide variety of different paved roadway environments.

Beneath the trailer cap was the power control unit for the RS-C and the data collection/control unit for the SSI GPR. Power was supplied by a 12V fast cycle marine grade battery, capable of supplying up to 3 hours of continuous power to both systems. A dual GPS antenna system was employed to provide a baseline for the inertial navigation system to correct trajectories from. The front antenna was mounted by suction cup on the front of the trailer cap and calibrated with the standard GAMS procedure. An Ethernet cable was run into the cab of the truck towing the system, where both RS-C and GPR were controlled from (**Figure 5**). Overall, data was collected at speeds ranging from 10kph up to 85kph, in both cases very successfully. Accuracy of the data is very well in line with the published specifications of both equipment manufacturers.

Figure 5

Data Post Processing

Once data was collected, the RS-C lidar and spherical imagery data was post processed to be co-registered into a single coordinate space (WGS 84) and later converted to a LAS format. This entire process required about 2-4 minutes for every minute of data collection, depending on the final deliverable data product, but is a very simple batch process which is typically done overnight for longer data collects. In this project, within one hour we had the first colour lidar dataset for visualization.

In the case of the GPR data, which is processed through SSI's Ekko Project software, there are more difficult considerations to be made based on earth type (clay, rock, sand, etc.), surface material (concrete, asphalt, gravel, etc) among others. This requires greater human expert intervention in the post processing phase. In all, within 12 hours we had our first set of co-referenced data. To merge the data into a single view, all data was converted to LAS format and viewed using the open source Cloud Compare software[6].

Data Visualization and Analysis

In designing this project, great consideration was placed on the number of GPR antennae to be used. While a larger number of sensors produces a closer to 3D subsurface view, it dramatically increases the need for data

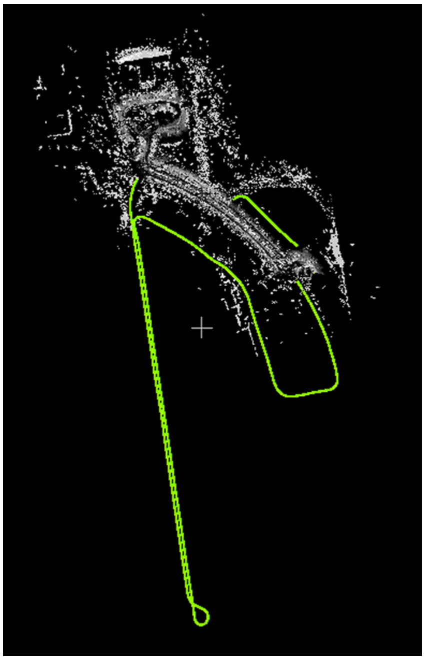


Figure 6

post processing time. Since we typically are looking only to identify the actual location of objects in comparison to existing drawings. Once a first evaluation is made if there are conflict between drawing and a "virtual inspection" from the mobile data , a further evaluation may warrant sending a crew onsite.

In a top view of the entire first day's drive (**Figure 6**), only a small portion of the overall pointcloud is included, as we specifically were looking for some features at the circular parking area in front of the soccer dome. The GPR track and drive trajectory are clearly seen in green. **Figure 7** & **8** is the view from within Siteco's standard Road-SIT Survey inspection software. What was noticed was that on Monday's first test run the soccer dome was inflated, by Wednesday morning it was gone! This is a prime example of the importance of change detection.

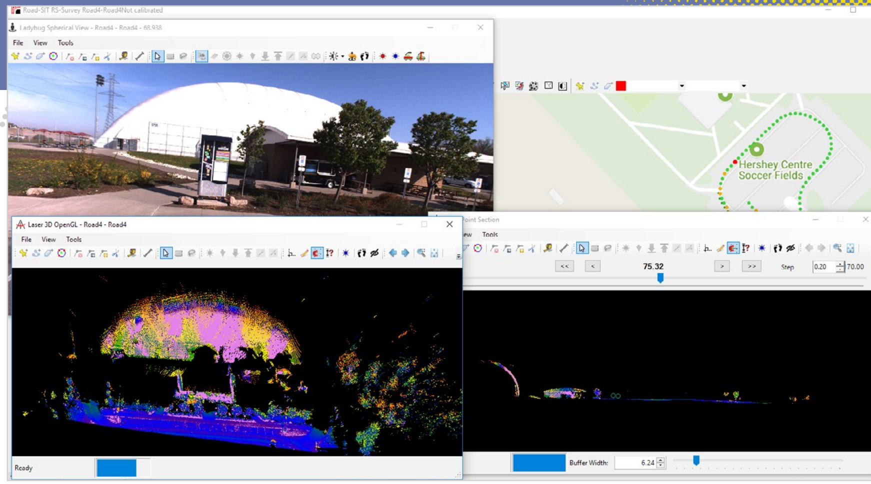


Figure 7

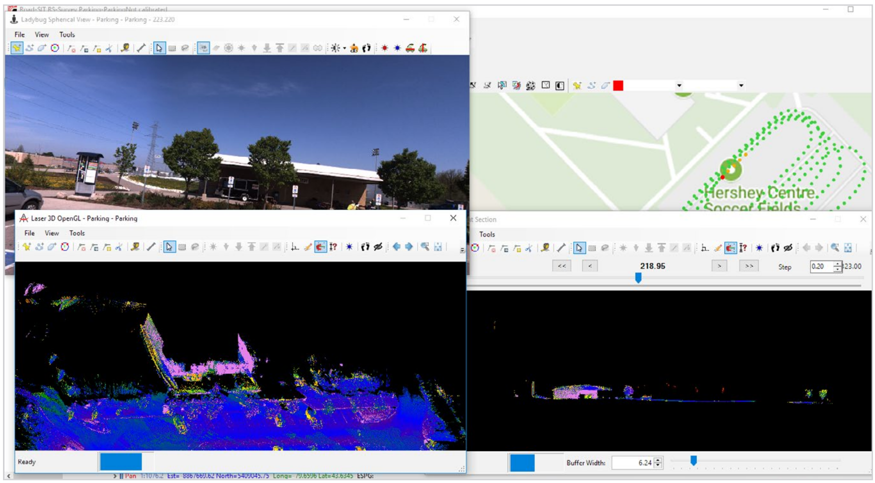


Figure 8

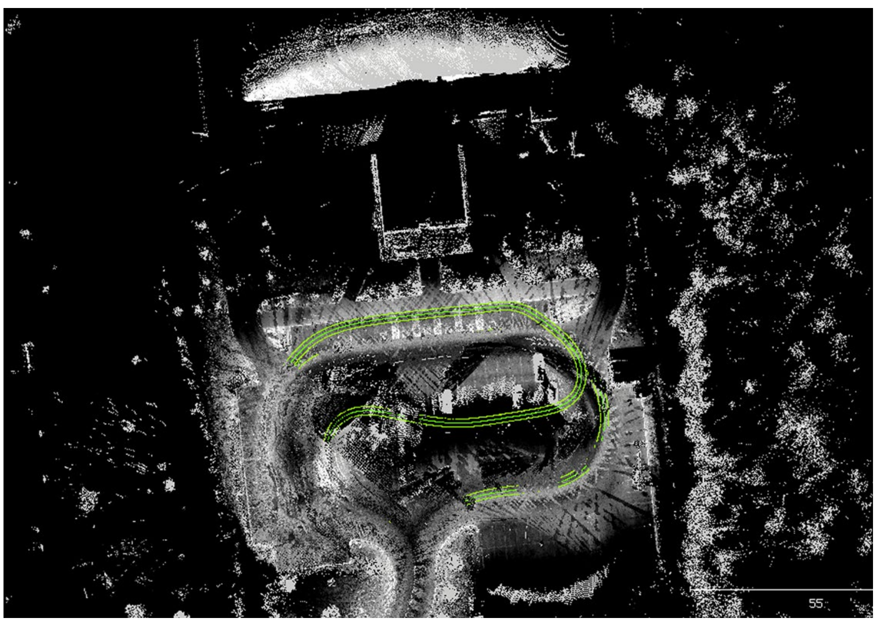


Figure 9

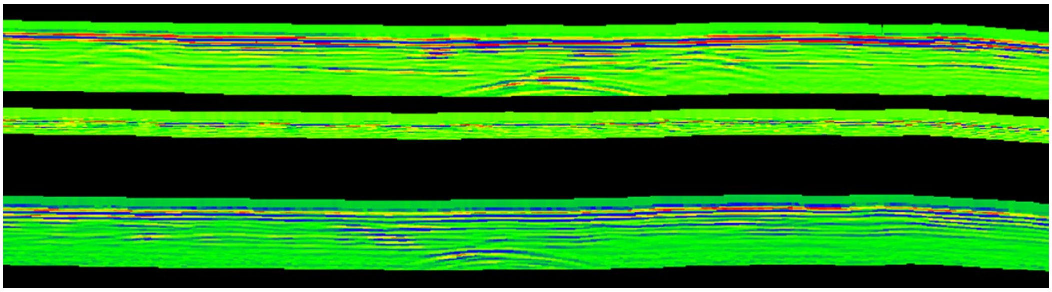


Figure 10

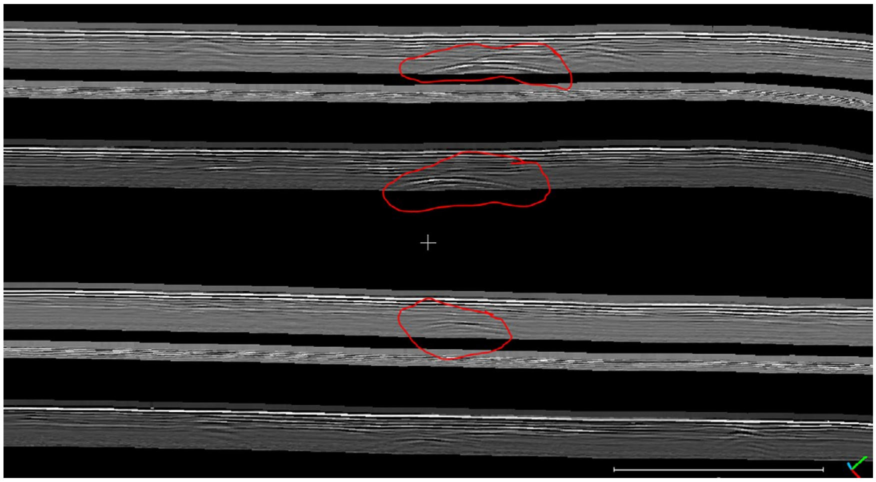


Figure 11

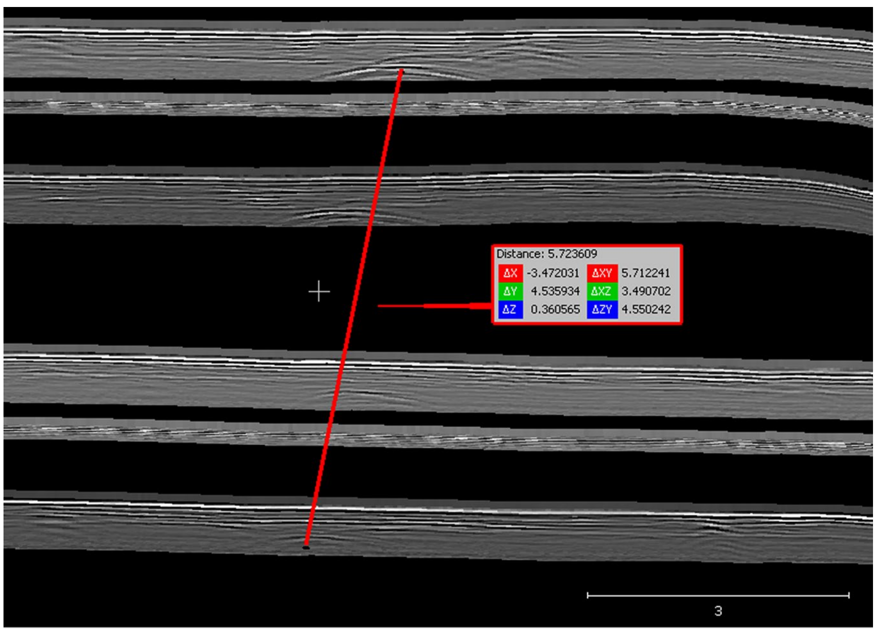


Figure 12

As we zoom in closer (**Figure 9**), clearly visible are the lidar intensity points, showing the markings on the parking lot area along with the 3 GPR data traces in green. These are very important to note as it allows for safe and very precise location of subsurface items. Zooming even closer to the surface, tilt the dataset, remove the lidar information(**Figure 10**), the central antenna is shown with it's much shorter range than the outside antennas on this single pass, due to the much higher frequency giving less depth penetration but higher resolution data.

When we widen the viewing area (**Figure 11**) and remove the colour lookup table, replacing it with the grey amplitude map of the radar (this is the more traditional method for visualization of GPR data in linear strips) across 2 separate data collection passes. Further analysis shows the buried power cable which is known to be in this area (**Figure 12**).

Our ultimate goal is to build all sensor interfaces directly into SITECO's Road-SIT Survey software, allowing concurrent and simultaneous data visualization. **Figure 13** is an example of an earlier successful experiment approx. 8 years ago, employing a Roadscanner 4 equipped with single FARO LS880 scanner, a surface profile rut bar (for

> “...a groundbreaking milestone in improving safety and data collection efficiency in the subsurface utility engineering and mapping (SUE/SUM) business community.”

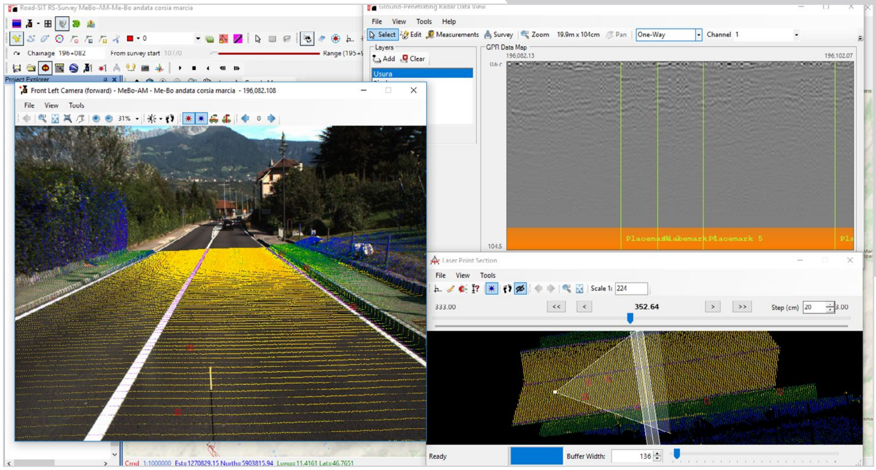


Figure 13

road surface planimetric measurement) and a single GPR antenna mounted on the front of the vehicle, however at much slower speeds. Clockwise from left is the front camera image with laser scan profile overlay and several placemarks on the roadway, next at top right is the radar image with the corresponding locations of the placemarks and lower right is a horizontal section at the road surface looking from above, again showing the placemark locations simultaneously.

There is considerable discussion of adding many GPR antennae to get a more comprehensive 3D view of the subsurface environment. We chose to employ three antennae as the data processing time is very compatible with the overall project requirements. The point is not to get a comprehensive 3D view, but to capture a “regional snapshot” where the major elements of interest (pipes, utility cables, voids indicating potential sinkholes, etc.) so a very precise location can be determined via the lidar data. This location information can be easily compared to existing and historic drawings, even directly within a GIS or CAD environment via the SITECO Road-SIT Survey software. The corresponding GPR data will help confirm the accuracy of the actual position, resulting in a much safer and better planned deployment of ground crews to investigate further before any actual digging commences.

Making the SUE/SUM Workspace Safer

In summary, this project was a complete success, simulating all of the capabilities as first stipulated. We feel this can be a groundbreaking milestone in improving safety and data collection efficiency in the subsurface utility engineering and mapping (SUE/SUM) business community. The project clearly demonstrated the comparison of data collected by traditional utility surveying methods and the ability to capture high-quality, reliable data from active roadways, at posted speed limits. This is an enormous step forward for utility surveying practitioners. Designers and engineers will have great insight into a project within hours or days of a survey as opposed to weeks or months. The existing software has demonstrated well established workflows that can be scaled up for very large projects.

Initial results were co-presented by Gelhar and Twohig at the SPAR 2018 conference on June 6th 2018 in Anaheim, CA, USA.

Brent Gelhar is a technology commercialization consultant based in Toronto, Canada. He has been involved in conceptualization, design, development and market rollout of static 3D scanners, mobile mapping systems and a wide variety airborne lidar systems while working at Optech Inc over a 10 year period. He currently is working with a variety of high technology startups, providing guidance to funding and market entry. Learn more at his website www.spatialinitiatives.org and his LinkedIn profile.

Endnotes

1 UK Health and Safety HSG47 (Third edition), originally published in 2014
2 Common Grounds Alliance, refer to the 2014 CGA “DIRT” Report
3 Common Ground Alliance (CGA) 2-14 SUE Best Practices 2016, Version13
4 MAPPS 2013 Government Affairs meeting.
5 http://sitecoinf.it/en/solutions/pave-scanner
6 https://www.cloudcompare.org/

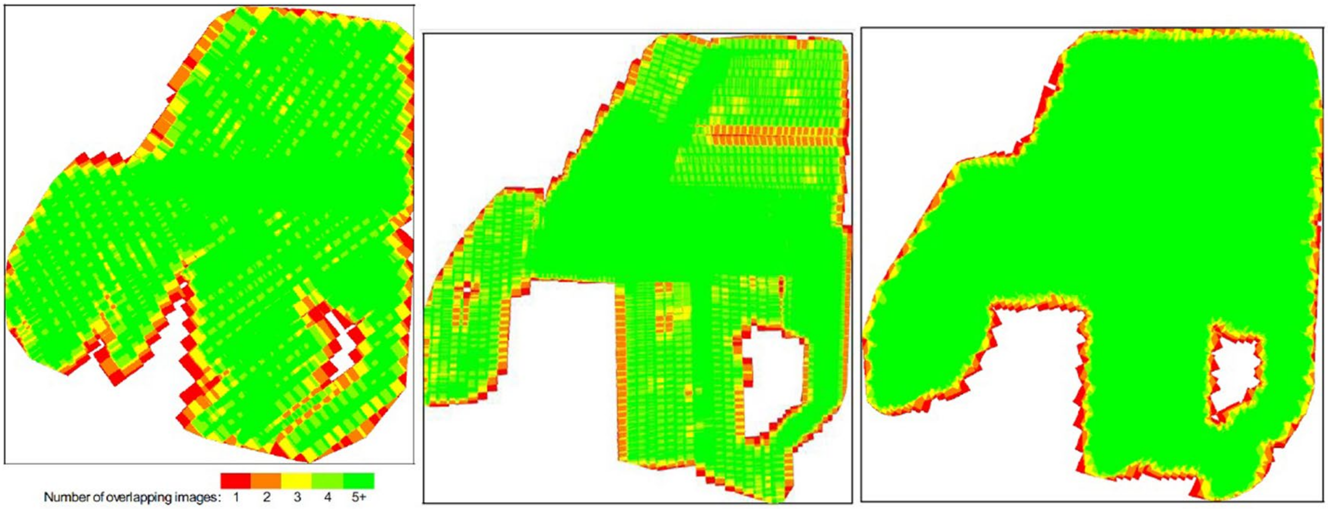


Figure 1: Comparison of the data coverage of the Inspire 2 (VTOL) high altitude, Inspire 2 (VTOL) low altitude and Altavian (Fixed wing) high altitude data collections. From a coverage perspective, green signifies "enough" while yellow is less than adequate and red is limited to none.

EVOLUTION OF POINT CLOUD

CONTINUED

In the first part of this paper, the various methods of creating point clouds from laser scanners and cameras were discussed. Additionally we explored the characteristics of point clouds by contrasting the differences between the photogrammetrically- and lidar-derived point clouds. In this article, we will evaluate the characteristics of the lidar and photogrammetric point clouds captured from different sensors/platforms: conventional lidar on a manned aircraft, UAS lidar and UAS camera. In order to conduct a comprehensive comparison, this study uses data collected at the same site. Qualitative and quantitative assessments have been applied to evaluate lidar and photogrammetric point clouds in terms of point density, data voids, visualization and completeness of the data. The accuracy comparison has been performed using a well-established control point layout consisting of control points and check points. The accuracy analysis is not covered in this paper. The study area is a 300 acre site in the Midwest.

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

Data sets collected and compared

Table 1 provides information on the sensors, aircraft and data collection parameters used in this study.

Ground control

As part of data processing, a set of 25 control points was established and approximately 75 photo-identifiable check points were also surveyed.

Manned/ Unmanned	Type	Aircraft	Sensor	Flying altitude (feet)	Side lap / End lap	Focal length / Mpix	No. of Lines	No. of Images	No. of Lifts
UAS	Fixed wing	Altavian Nova F6500	Canon EOS Rebel SL1 camera	170	70%/70%	20 mm/17	~73	4772	3
UAS	Fixed wing	Altavian Nova F6500	Canon EOS Rebel SL1 camera	400	70%/70%	20 mm/17	39	1385	1
UAS	Multi rotor	DJI Inspire	X5s camera	210	70%/70%	15mm/20	~80	2574	7
UAS	Multi rotor	DJI Inspire	X5s Camera	400	70%/70%	15mm/20	47	790	4
UAS	Single rotor	Vapor 55	Rigel VUX lidar	125	20^0 side lap		30	n/a	2
UAS	Single rotor	Vapor 55	Rigel VUX lidar	300	20^0 side lap		11	n/a	3
Manned	Fixed wing	Navajo	Leica ALS70 lidar	1150	30^0 side lap		13	n/a	1
Manned	Fixed wing	Navajo	Leica RCD 30 Camera	2500	60%/30%	53 mm	5	80	1

Table 1: Aircraft and sensors used in the project along with the flight lines and number of images

Data processing

The data processing of images collected using Altavian and Inspire systems was performed using the Pix4D software. The Altavian Nova's integrated GPS was post-processed to improve positioning of each frame. All imagery was then run through a Pix4D workflow to produce DEMs and orthophotography. The DJI Inspire 2's integrated GPS data was not post-processed. All the Inspire 2 imagery was run through the same Pix4D workflow to produce DEMs and orthophotography. The lidar data collected from fixed wing and UAS was processed using a multitude of software packages including Geocue andTerrasolid. All the datasets were processed using a similar number of control points. Grids with 0.2 ft resolution were generated. The Z value comparison was made on all the grids.

Comparison of different data

The resultant point clouds from each sensor / platform were compared with respect to number of points, point density, point spacing, and data voids. Visual analysis was also performed to compare the different datasets.

Point density comparison

Point density is related to point spacing and logically the closer points are to one another, the higher the point density and *vice versa*. The point density is normally calculated from the actual data using the "box counting" method, whereby an area of a rectangle is associated with the total number of lidar points inside the rectangle. In the case of lidar scanners, point density is a function of flying altitude, pulse rate, scan rate, and scan angle. Point distributions are rarely regularly or evenly spaced. As a rule of thumb, the more points that are reflected from a target, the better we define that target. Point spacing refers to one-dimensional measurement or a point-to-point distance. The point spacing varies depending on the application and type of deliverables. Point spacing also determines the necessity for the delineation of linear features, such as breaklines, as a supplemental deliverable.

The point density of the photogrammetric point cloud is comparable to the point density of the lidar point cloud (**Table 2**) and in some cases it is much higher. The point densities of the point clouds from the Altavian and Inspire at low altitude are 392 and 381 respectively, compared to 278 for the UAS lidar point cloud, and nearly 5 times denser than the fixed wing lidar flown at 1150 feet. The point spacing is also comparable to the lidar.

The LAS files created from different collections were processed for ground points only and a grid 0.2 ft has been created. The minimum and maximum elevation were also compared from the grids and are given in **Table 3**.

The Z values are consistent except for Inspire 2. During the data collection using Inspire, there were some issues

	LiDAR based Point Cloud			Imagery based Point cloud			
	Navajo (fixed wing) -LiDAR	Vapor 55 (UAS) - LiDAR_High	Vapor 55 (UAS) - LiDAR_Low	Nova (UAS) - Camera_High	Nova (UAS) - Camera_Low	Inspire 2 (UAS) - Camera_High	Inspire 2 (UAS) - Camera_Low
LiDAR Point Count	90,366,682	153,672,370	250,445,873	129,485,687	576,600,005	140,659,028	428,138,933
LiDAR Point Density (Points/M^2)	81	145	277	86	391	102	380
LiDAR Point Spacing (	0.1109	0.083	0.06	0.1074	0.0505	0.0989	0.0512

Table 2: Point cloud characteristics from different platforms/sensors/altitudes

that caused inconsistent elevation values. These effects are discussed below.

Completeness and data void

A data void can occur in lidar data for a number of reasons including water absorption. Lidar data voids may be natural (e.g., water bodies or fresh asphalt that absorbs the laser energy), unintentional (e.g., high winds or navigation errors that cause gaps between flight lines), or intentional (e.g., from post-processing for deliberate removal of manmade structures and/or dense vegetation not penetrated by the lidar). The uniformity of the point density throughout the dataset is important.

Likewise, data voids in point clouds created by photogrammetry may occur for the following reasons: issues related to data collection and processing; terrain conditions, including tree cover and surface texture.

With respect to data collection, the following parameters play a role in getting a consistent and accurate photogrammetric point cloud: overlap; motion blur; rolling shutter effects; ground sample distance (GSD).

> “The point density of the photogrammetric point cloud is comparable or even better than the point density obtained from LiDAR.”

Terrain conditions, including tree cover and surface texture, are very significant. Vegetation (e.g., trees, crops) cover has an important impact on photogrammetric point clouds as explained in the first part of the article.

	LiDAR based Point Cloud			Imagery based Point cloud			
	Navajo (fixed wing) - LiDAR	Vapor 55 (UAS) - LiDAR_High	Vapor 55 (UAS) - LiDAR_Low	Nova (UAS) - Camera_High	Nova (UAS) - Camera_Low	Inspire 2 (UAS) - Camera_High	Inspire 2 (UAS) - Camera_Low
Min Elevation (ft.)	940.89	950.38	957.61	941.41	939.4	919.92	921.25
Max Elevation (ft.)	987.35	987.37	986.9	987.16	987.36	987.87	987.85

Table 3: Minimum and maximum elevation comparison of the grids created from different point clouds.

The texture of the surface from which points are derived has a big impact on whether voids are created. For example, large rooftops with smooth texture are likely to produce a data void in the resulting point cloud. Wind causes vegetation canopies to move during image acquisition, which causes positional and spectral (reflectance) changes in these features between images, and often result in data voids.

Data Processing related

One of the most important issues related to data processing is key point matches, which affect the generation of consistent point clouds from imagery using SfM. The image contrast and quality significantly affect keypoint matches.

The data collected using the DJI Inspire 2 illustrates well several data collection and data processing problems that have measurable effects on the quality of the resultant photogrammetric point cloud. During the data collection, a number of factors contributed to inadequate overlap of approximately 5 photos. These gaps in coverage then caused difficulty in triangulating those photos and adjacent photos. The complete coverage using 400’ & 200’ AGL Inspire 2, and the 400’ AGL fixed-wing is shown in **Figure 1**. The “green” indicates enough coverage, “yellow” indicates less than the adequate number of images and “red “indicates practically no or very small number

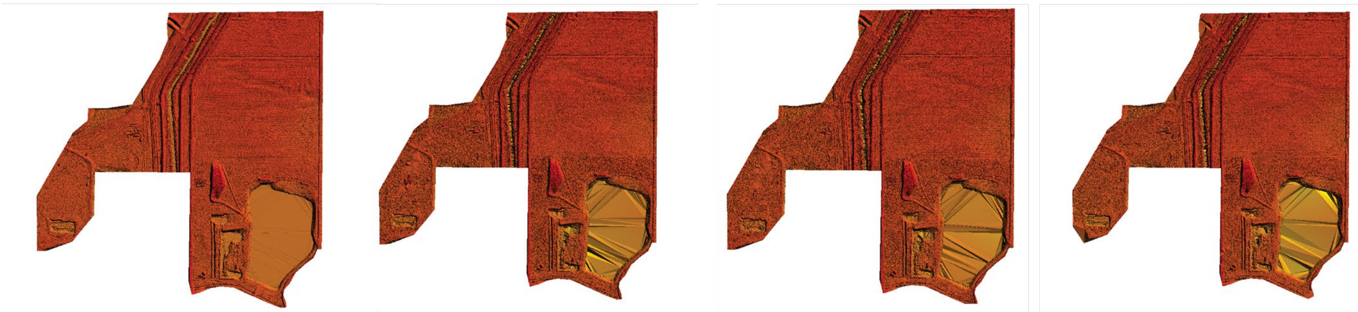


Figure 2: Grids generated from the ground points of the LAS files from 7 different collections. Derivative products like elevation grids and (subsequently) contours can be created from both the point clouds.

of images. The UAS fixed wing coverage is complete as can be seen from the "green wash" and yielded a consistent point cloud.

The grids created from all the seven different point cloud from imagery and lidar sensor are shown in **Figure 2**.

Conclusion

UAS data processing software products that use either semi-global matching (SGM) or SfM methods to generate point clouds have given rebirth to photogrammetry. UAS-based data collection and processing has become another tool for professionals practicing geomatics. Whenprofessionals understand the important distinctions of each technology, they will be better able to apply the right tool to the right project for optimum results.

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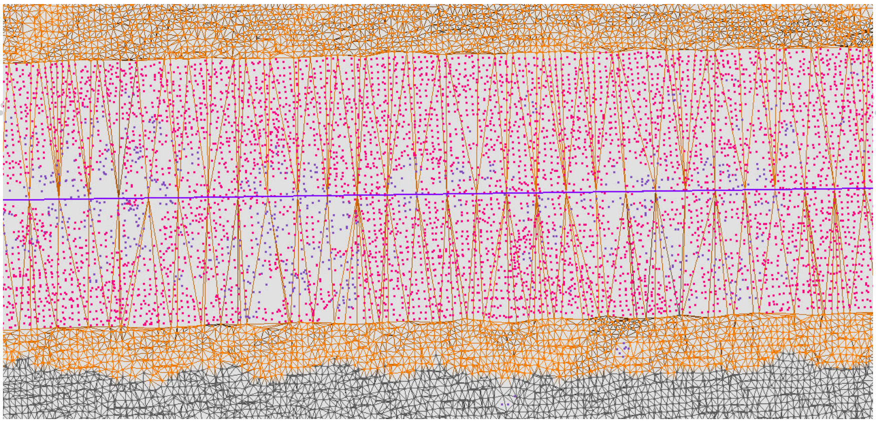

Figure 2: A downstream constraint (purple line) in dense data

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moving unclassified points to an unused class. This class (magenta points) as well as low noise points (purple points) are being withheld from the TIN (faint orange lines). If this constrained model were used to generate an exported DEM, the elevation posts would faithfully obey our desired downstream model.

This is just a very basic introduction to the concept of breaklines. If you are generating derivative products from point cloud data, you will need tools that can both create and enforce the variety of constraints needed for your particular situation. You can read much more about breaklines in our GeoCue knowledge base (www.geocue.com). Till next time, stay between the lines!

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LEWIS GRAHAM

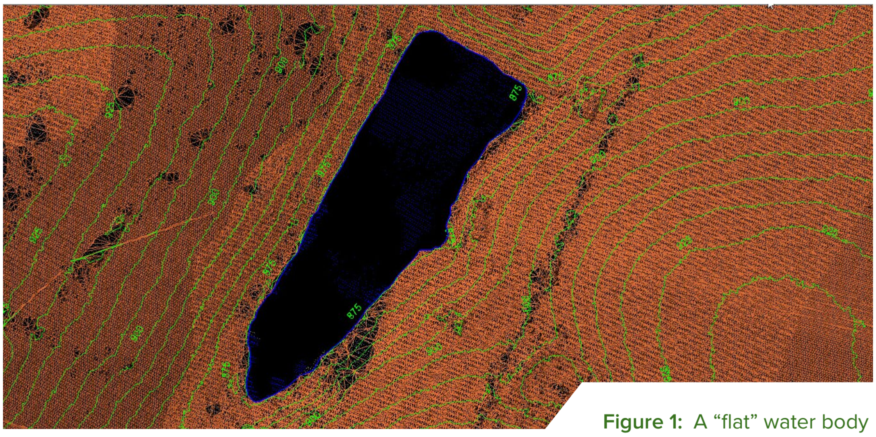

Figure 1: A "flat" water body

You are breaking up!

I am writing this from our summer camp on Lake Wheeler in northern Alabama. After a hard day of playing on the lake with all the kids, a bit of writing is a respite!

I am conducting a seminar on point cloud model constraints in a few weeks so I thought I would devote this column to some thoughts on the impact of high density data on constraint modeling.

Geometric model *constraints* are data that we inject into a point cloud to force some sort of geometric conformance that is not in the original point cloud data. In the GIS world, these constraints are commonly referred to as *breaklines*, a bit of a misnomer since constraints can take the form of points and polygons, in addition to polylines. One commonly recognized constraint is the shoreline of a static water body such as a pond. Still water must be level so every point of the shoreline must be at the same elevation relative to a gravitational model (geoidal heights). Such a constraint is often referred to as water body flattening. In **Figure 1** is depicted a pond with the shoreline demarked by a polygonal breakline (blue), forcing the elevation to 875 feet. Notice that the dynamic contours (GeoCue's LP360 is the modeling tool) are obeying the constraint of the flattening breakline.

Model constraints generally do not modify the point cloud itself. They modify the triangulated irregular network (TIN) rendering of the cloud by forcing new edges or vertices into the model. Derived products such as digital elevation models (DEM) or contours are generated under the influence of these constraints. The idea is that we are adding information to the model that is not present in the original point data. This is a fascinating approach because it is a way around the famous Nyquist sampling criteria that says we must sample at a rate twice the resolution of the finest detail we hope to model.

Often this auxiliary information that we inject into the model is inferential. An example is a flowing stream. We know streams flow downhill even though the point cloud data do not reveal this in many areas of the model due to noise, vegetation and other model interference. By adding a downstream constrained stream centerline (the "talweg"), we can force the correct hydro behavior on our model.

There are also situations where supplementary data being injected in the model are physically measured. An example is supplementing dense image matching data (from drone mapping operations) in vegetated areas. RTK survey points from a "pogo" survey of the ground can be injected into the point cloud model as mass points. For projects that are mostly clear of vegetation, this can be a more economical approach of modeling small obscured areas than LIDAR mapping.

The very dense data from drone-based low precision laser scanners (those with precision on the order of 5 cm, at one sigma) and structure from motion (SfM) point clouds must be treated in special ways when adding breaklines to models. The peak to peak excursions of data with a 5 cm (1 sigma) precision will be about 30 cm. Draping a stream centerline over a TIN modeled on these data will be far too noisy to model a downstream constraint. The standard practice with point cloud data is to omit points rather than manipulate the geometry of the points. Thus your modeling software will need to be capable of operations such as "use mean Z" or "use median Z" when working with these type data. A second consideration is the high data density. Adding a constraint edge into the TIN will not have much of an effect if the triangles are small relative to the feature that you are trying to model. One way to overcome this problem is to suppress points near the breakline from being included in the TIN model. This approach is depicted in **Figure 2**. Here we have created a point buffer around the downstream breakline (purple line) by

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