LIDAR MAGAZINE

VOLUME 8 ISSUE 3
MAY/JUNE 2018

SENSOR FUSION

22 ASPRS HELPS GUIDE LIDAR
Providing a forum for the dissemination of information regarding best practices with kinematic laser scanners

34 THE EVOLUTION OF *RIEGL*
Highlighting key milestones and innovations that led to the development of the groundbreaking miniVUX-1UAV

44 FUTURE SURVEY BLUEPRINT
Lidar technology has vastly improved one firm's ability to conduct monitoring surveys in vulnerable coastal regions

LIDAR MAGAZINE

IN THIS ISSUE

14 Fusion of Sensor Data Advances Geospatial Technology

The steady climb up the slope of improving sensor technology is generating better geospatial solutions, especially in mobile mapping and machine control, and as a result, improving workflows, productivity and project outcomes. What is most exciting about data collection right now is the potential to bring together multiple different sensor types or technologies to advance geospatial solutions in the areas of cost, performance, availability and reliability.

BY SHAWN WEISENBURGER

22 How ASPRS Helps Guide the Lidar Industry

The American Society for Photogrammetry and Remote Sensing (ASPRS) is organized to be responsive to the various types of remote sensing and mapping technologies, and currently has seven professional divisions: the GIS Division; the Lidar Division; the Photogrammetric Applications Division (PAD); the Primary Data Acquisition Division (PDAD); the Professional Practice Division (PPD); the Remote Sensing Applications Division (RSAD); and the Unmanned Autonomous Systems Division (UASD).

BY DR. JASON STOKER

28 Airborne Lidar Flies High in Manitoba

The rising popularity of surveys using UAVs has led to great advances in photogrammetric techniques. Airborne lidar, however, still leads the way when it comes to collecting data across large geographical areas where elevation data is critical in places where foliage and vegetation can obstruct a standard camera's view.

BY MADELEINE LAKE

34 Charting the Evolution of *RIEGL* Sensors and Systems

Over the last five decades, few can claim to have devoted more to the development of lidar technology than Dr. Johannes Riegl, founder and CEO of the *RIEGL* group. The miniVUX-1UAV is a recent example of his team's unique insight and ability. Prior to founding his namesake firm, Dr. Riegl focused on research and development work at the Vienna University of Technology from 1968-78.

BY JAMES WILDER YOUNG

39 Capturing the Past: Historic Livermore Winery Lives On

For more than a century now the 4-watt light bulb, called the Centennial Light, has been burning since it was first clicked on in 1901. Housed in the Livermore-Pleasanton Fire Department Station #6, it glows dimly, but still functions as a light bulb. The Livermore community has other historical phenomena of note, including a historic building on the grounds of the Sycamore Grove Park.

BY JEFF WINKE

44 Coastal Monitoring Project Provides Blueprint for Future Surveys

Though it happened almost 25 years ago, the dramatic collapse of Holbeck Hall Hotel in Scarborough, United Kingdom remains a pertinent reminder of just how unstable coastlines can be. In the weeks beforehand, cracks had been reported, but the subsequent landslide forced guests and staff to flee quickly. Later, the British Geological Survey attributed this extraordinary event to a combination of heavy rainfall drainage issues and water pressure.

BY JOE BEECHING

COLUMNS

2 ***From the Editor:*** Unexpected Nuggets

BY DR. A. STEWART WALKER

10 ***Book Review***

A review of "LiDAR Remote Sensing and Applications" from CRC Press

12 ***Points & Pixels***

Coverage of unique projects and news from around the lidar world.

DEPARTMENTS

48 ***Random Points:*** Convoluted Thinking

BY LEWIS GRAHAM

LIDAR To Go!

Get the most from this magazine on your tablet or laptop.

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

DR. A. STEWART WALKER

Unexpected Nuggets

This month's editorial is a tad threadbare because I have been on a long vacation in Europe, but this was not without its lidar-related moments. For the first time since I was a child, I visited Culloden, the site of a battle in 1746 in which a dissenting minority of the Scots (mainly the Highland clans), who were supporting the (Catholic) Jacobite Stewarts, were routed by the English. As I was leaving the excellent visitor center to step out on to the battlefield itself, I noticed a display by Forestry Commission Scotland, the organization that manages public forests. A transportation network was built in Scotland, begun after the previous Jacobite rebellion of 1715, often called General Wade's Roads after their creator, to connect several fortified barracks and facilitate the movement of military personnel and materiel. After Culloden, these roads were used to advantage by General William Augustus "Butcher" Cumberland (1721-65), the victor at Culloden, who subjected the Scots to a repressive regime, including civil penalties, burning of crops and homes, looting and forced emigration, to weaken Gaelic culture and undermine the clan system that was prevalent in the Highlands of Scotland, to ensure that the dissent would not be repeated. The network was extended from 1740 to 1767 by Major William Caulfield and there are numerous bridges, some of which still exist. Those in Achlain Forest have been thoroughly investigated and surveyed prior to restoration. The display in the visitor center showed a lidar scan of one of them, so the enormous numbers of tourists to this critical historical site are seeing our technology's value in critical conservation work.

Before reaching Culloden, I attended a reunion of my undergraduate geography class at the University of Glasgow (45 years, so the male students were showing considerable hair loss) and visited my mentor, Professor Gordon Petrie. During our long conversation, I extracted an undertaking from him to write one or two articles for the magazine, so we look forward to that. We talked, of course, about how to spell the name of our technology—a debate I opened in my last editorial - and, as I expected, he is firmly in the "lidar" camp. He followed up with an e-mail and produced a complete lecture (see sidebar). I set things in motion in the March/April issue, but now the debate is far better informed. The "lidar people" remain in the ascendancy! Thank you, Gordon, for furthering the education of your student and his readers.

One of the pleasures of a vacation is returning home to a stack of unread copies of *The Economist* and yet again lidar hits the headlines. In the issue of 7 April 2018, a piece entitled "The art of reflection" examines the colors of cars, starting with Henry Ford's predilection for black. It transpires that dark colors not only absorb sunlight, but

LIDAR MAGAZINE

www.lidarmag.com

2018 Vol. 8 No. 3
© Spatial Media LLC

PUBLISHER Allen E. Cheves
publisher@spatialmedia.us

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

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

CONTRIBUTING WRITERS
Marco Cecala
Dr. Srini Dharmapuri
Jeff Fagerman
Lewis Graham
Ted Knaak
Dr. David Maune
Jarlath O'Neil-Dunne
Michael Raphael
John Russo
Karen Shuckman
Ken Smerz
Paul Tice
Larry Trojak
James Wilder Young

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

GRAPHIC DESIGN LTD Creative, LLC
WEBMASTER Joel Cheves
AUDIENCE DEVELOPMENT Edward Duff
MEDIA RELATIONS Richard Bremer

LIDAR Magazine is published 8x annually by Spatial Media LLC. Editorial mailing address: 7820 B Wormans Mill Road, #236 Frederick, MD 21701. Tel: (301) 620-0784; Fax: (301) 695-1538. No part of this publication may be reproduced in any form without the express written permission of the publisher. Opinions and statements made by the writers and contributors do not necessarily express the views of Spatial Media LLC.

Subscribe @ www.lidarmag.com

Made in the United States of America

OFFICIAL PUBLICATION

SPATIAL MEDIA

USIBD U.S. Institute of BUILDING DOCUMENTATION

HARRIS®

TECHNOLOGY TO CONNECT,
INFORM AND PROTECT™

CHANGE THE WAY YOU USE LIDAR

After two decades of providing the U.S. Government with Geiger-mode LiDAR data, Harris Geospatial Solutions is now offering its high-resolution LiDAR data and products to commercial organizations and civil governments. Our Geiger-mode LiDAR sensors can quickly collect data on a larger scale and at higher-point density than has been possible up until now. This provides you with actionable information to make smarter operational and business decisions for applications from flood modeling to transmission line monitoring.

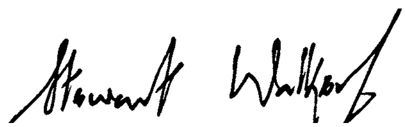
harrisgeospatial.com/lidar

FROM THE EDITOR

also much of the signal transmitted by radar and lidar sensors on other cars. The author must have read last month's article on Cepton, however, because he notes that "miniature versions are being developed" to supersede existing systems, because, "At present, lidar is big and bulky (the blob-shaped roof racks on self-driving cars are lidar sets)". Ideally, cars should all be painted in colors that strongly reflect the radar and lidar signals, but that is unlikely as owners have feelings about colors. PPG, a Pittsburgh supplier of paints and coatings, is researching paint modifications at the molecular level so that high reflectivity is maintained regardless of how the color appears to the human eye. Their techniques are based on how the aubergine (eggplant) works: infrared radiation passes through its black skin and is reflected by the white flesh inside, so the plant remains cool in the summer. PPG uses this approach to keep aircraft cool even if they are painted in dark colors and it is but a step to develop paints for cars that retain high reflectivity. Similarly, road signs can be painted so that they are bright and easily readable by humans yet do not blind lidars. In the issue of 22nd March, a report on the tragedy caused by an Uber autonomous vehicle (AV) noted that Arizona is attractive for testing AVs as it is warm and "snow can confuse the LIDAR sensors [that] AVs use to scan their surroundings". I wonder whether in fact the lidar measures the snow surface correctly but, of course, the result will not match the system's database of road topography and roadside features.

There is a new feature in this issue—a book review. The publishers contacted me and asked if we would be interested, so I said yes. I reviewed this one myself, but if any readers are interested in writing reviews of other books, please let me know. We will review only books with substantial lidar content: other periodicals, such as *PE&RS* and *The Photogrammetric Record*, include excellent reviews of a broader range of geomatics books, so we can afford to be choosy!

On 20 April 2018, I attended an ASPRS Pacific Southwest Region Technical Meeting, held at San Diego State University. Four presenters offered a variety of fare to an audience consisting of SDSU faculty and graduate students plus a handful of local ASPRS members. One described combining lidar and imagery to monitor ecosystem changes resulting from drought, shorter inter-fire intervals and human intervention. Another talked about a traditional aerial photography business, with a long history of film sensors, using digital sensors and lidar for the first time. I met a local drone start-up. This was a worthwhile afternoon and I'm pursuing some of the *dramatis personae* for articles—local meetings often yield unexpected nuggets!



A. Stewart Walker // Managing Editor

The spelling and useage of "lidar" BY GORDON PETRIE

I would like to respond and give my thoughts on the matter of "lidar" and its usage, besides the matter of its spelling. I am completely in agreement with your correspondent, Dr. Stoker. As far as I am concerned, "lidar" should be treated just like "radar" and "sonar". Furthermore, I feel that attempts to keep up a fancy spelling such as "LiDAR" are, quite simply, doomed to failure. Down the line, popular usage will cause "lidar" to become standard, just like "radar"—at least in my opinion! However, I would like to point out the use of the term by NASA, which, after all, is the organization that is responsible for so much of the development of the laser-based ranging technology that is used for mapping.

I. NASA describes all the devices that carry out laser profiling and scanning for topographic mapping applications from space as "laser altimeters", not "lidars":

- i. "Shuttle Laser Altimeter" (SLA) mounted on two Shuttle flights during the 1990s
- ii. "Geoscience Laser Altimeter System" (GLAS) mounted on the Earth-orbiting ICESat
- iii. "Mars Orbiter Laser Altimeter" (MOLA) mounted on both the Mars Observer and the Mars Global Surveyor missions
- iv. "Mercury Laser Altimeter" (MLA) on the Mercury Messenger mission
- v. "Lunar Orbiter Laser Altimeter" (LOLA) on the Lunar Reconnaissance mission.

They all use the term "laser altimeter" and the letters "LA" in their acronyms. "Lidar" is never mentioned anywhere.

II. On the other hand, the laser ranging devices that are used by NASA for research into the tropospheric, mesospheric, and stratospheric layers of the atmosphere that exist around the Earth, i.e. to research into objects such as clouds, winds and aerosols, are invariably called "lidars":

continued on page 8

HARRIS®

TECHNOLOGY TO CONNECT,
INFORM AND PROTECT™

GET CRUCIAL, TIMELY INFORMATION FROM YOUR LIDAR DATA

The world is not flat. You need a software solution that lets you see the world as it is, not in just two-dimensions. ENVI® software makes it easy to use LiDAR to extract 3D features and create digital elevation or surface models (DEM/DSM) so you can perform terrain and line-of-site assessments, create forest inventories, extract building footprints, or even determine vegetation encroachment on power lines.

harrisgeospatial.com/envi

ENVI®

i. "Tropospheric Ozone Differential Absorption Lidar" (TROPOZ DIAL) from Goddard Space Flight Center (GSFC)
ii. "Langley Mobile Ozone Lidar" (LMOL) from Langley Research Center (LRC)
iii. "Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation" (CALIPSO), also from LRC
iv. "Cloud Physics Lidar" (CPL), being flown on the high-flying NASA ER-2 (U-2) aircraft
v. "Tropospheric Wind Lidar Technology Experiment" (TWiLiTE), which is an airborne Doppler 'lidar' designed to measure wind profiles in clear air from 18 km to the Earth's surface. It is operated by GSFC from high-flying aircraft such as NASA's DC-8, ER-2 and Global Hawk.
vi. "Goddard Lidar Observatory for Wind" (GLOW), also employed by GSFC
vii. "Micro-Pulse Lidar Network" (MPLNET), which is a ground-based network of Micro-Pulse Lidar (MPL) systems run by GSFC. It is designed to measure aerosol and cloud vertical structures and boundary layer heights. The data are collected continuously, day and night, over long time periods from various ground sites around the World.
viii. "Lidar In-Space Technology Experiment" (LITE) that was mounted on the Shuttle Discovery, again operated by LRC
ix. "Differential Absorption Lidar" (DIAL). These are ground-based systems that have been measuring stratospheric ozone and middle atmospheric temperature from the JPL-Table Mountain Facility since 1988. Another DIAL system has been operating at the Mauna Loa Observatory, Hawaii since 1993.

From the above, it appears that NASA makes a clear distinction between its laser ranging devices mounted on spacecraft and aircraft and on the ground on the basis of their applications - "laser altimeter" if used for the measurement of topography and "lidar" if used for atmospheric research.

III. However, there are two or three older laser ranging devices and systems that have been designed and operated by NASA on aircraft that don't adhere to this policy:

i. "Experimental Advanced Airborne Research Lidar" (EAARL), which is a bathymetric laser scanner used for shallow-water coastal surveys
ii. "Airborne Oceanographic Lidar" (AOL), an early bathymetric profiler and scanner used from the 1980s onwards
iii. "Scanning Lidar Imager of Canopies by Echo Recovery" (SLICER), which is based on the older "Airborne Topographic Laser Altimeter System" (ATLAS) [Note again the use of "LA" in the acronym!].

As far as I am aware, the first two of these older devices were designed and operated by the Wallops Flight Facility in Virginia, rather than one of the mainstream NASA research centers such as GSFC, LRC or JPL. I am fairly sure that GSFC developed the SLICER, but I am not sure whether Wallops was involved with the original ATLAS on which it was based.

IV. This leads me to the titles of the more recent NASA airborne instruments and systems featuring a pushbroom (i.e. non-scanning) type of swath mapping of the Earth's topography, instead of the conventional cross-track laser scanning:

i. "Slope Imaging Multi-Polarization Photon-counting Lidar" (SIMPL)
ii. Multiple Altimeter Beam Experimental Lidar" (MABEL)
iii. "Airborne LIST Simulator" (ALISTS), which is oriented specifically towards satisfying the requirements of the proposed LIST (Lidar Surface Topography) mission, which would utilize a wide-swath non-scanning multi-beam lidar mounted on a satellite to map the Earth's solid (land and ice) topography and vegetation on a global scale from space.

Partly as a result of all of these considerations, I have tried to avoid using the word "lidar" in my chapters of the *Topographic Laser Ranging and Scanning* book[1]. Wherever possible, I use "laser ranging", "laser profiling" and "laser scanning", depending on what is being discussed. It was quite impossible, however, to avoid using "lidar" altogether. As Dr. Stoker has also pointed out, "lidar" is used (i) as part of the name of several commercial instruments and systems; and (ii) in the titles of a number of the papers that have been quoted in the text and therefore appear in the list of references at the end of each of the chapters.

So, before you embark on your editorial that is designed to stimulate a discussion about the 'Spelling of LiDAR', you may also want to consider the various closely related matters about the usage of "lidar" that I have raised above.

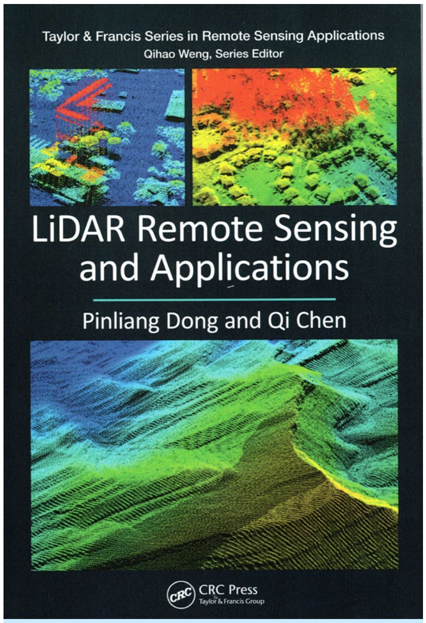
Gordon Petrie is emeritus professor of topographic science at the University of Glasgow in Scotland. He joined the University in 1958 after a short career as a professional land surveyor with the U.K. Directorate of Overseas Surveys, working mainly in Yemen. He taught and researched in photogrammetry, remote sensing and surveying in Glasgow until his retirement, but continues to write and research extensively, for example on the history of mapping and on photogrammetric and laser instrumentation. Gordon has had strong connections with the U.S.A. through his frequent participation in academic and professional meetings and his spells as visiting professor at the University of Georgia (twice) and Miami University of Ohio. He received the Fairchild Photogrammetric Award from ASPRS in 2008 and has also been the recipient of the President's Medal by the U.K. Photogrammetric Society and the Bartholomew Globe by the Royal Scottish Geographical Society. Together with his co-author, Professor Charles Toth of Ohio State University, he has contributed the first three chapters on laser instrumentation to the book on *Topographic Laser Ranging and Scanning* (see above).

---

1 Shan, J. and C.K. Toth (eds.), 2018. *Topographic Laser Ranging and Scanning: Principles and Processing*, Second Edition, CRC Press, Boca Raton, FL, 654 pp.

BY DR. A. STEWART WALKER

LiDAR Remote Sensing and Applications



Pinliang Dong and Qi Chen.
CRC Press, Taylor & Francis Group,
Boca Raton, Florida, 2018.
232 x 155 mm, xix + 200 pp,
40 color + 143 black and white
illustrations, index.
Paperback, ISBN 978-1-138-74724-1,
$75.96.

The authors of this short, newly published book are full professors, Dong at University of North Texas and Chen, University of Hawaii. Both earned BSc and MSc degrees in China then moved to North America for PhDs. Both have published widely on *applications* of remote sensing and this is reflected in the book's emphasis on the utilization of lidar. Their goal was to introduce LiDAR technology then cover forestry, urban and geoscience applications for a senior undergraduate and graduate audience. More than 500 up-to-date references are a boon and a key feature is the use of 27 lidar data sets, many of them in projects (the authors' word for case studies), in which the reader is conducted step-by-step through data processing, mainly in ArcGIS® but sometimes in readily available freeware, then asked questions to test understanding. The data sets and related files for the projects are at geography.unt.edu/~pdong/LiDAR/.

The structure of the book is straightforward. It begins with a short introduction to remote sensing, in which lidar is placed in context alongside multispectral, hyperspectral and SAR technologies. The explanation of SAR is less accessible than the rest of the book and there is no mention of today's constellations of high-resolution SAR birds. The assertion on page 1 that analog aerial photographs are uncalibrated is incorrect. A comment on the cost of aerial photography on page 4 insufficiently takes into account the increasingly popular "fly once, sell many times" model and the impact of UAVs. Those hoping for insights into full waveform lidar will be equally disappointed as the authors explain why only discrete-return lidar is covered, though both modes are described in chapter 2, which covers lidar principles, accuracy, data formats and resources. Similarly, prospective readers who construed the first three words of the title as implying detailed coverage of multispectral lidar must look elsewhere. Some reference to modern accuracy standards such as the USGS base specification would be helpful. The material on currently available systems is woefully brief and—perhaps unsurprisingly in view of the application areas described—there is no mention of bathymetric lidar. Three of the book's 11 projects are in this chapter, for example exploring a lidar data set for the Mānao campus of the University of Hawaii. The third chapter focuses on lidar data processing, including filtering, classification and interpolation, illustrated by two more projects. Note that these three chapters comprise only 62 pages in all: this book is not intended to be a detailed text on lidar technology for geomatics specialists, but an introduction to enable students in other fields to understand and use lidar data. Specialists have other resources, for example the recently published second edition of *Topographic Laser Ranging and Scanning: Principles and Processing*, edited by Jie Shan and Charles K. Toth (also CRC Press).

There follow three chapters on forest, urban and geoscience applications. These are the heart of the book. The authors are at home in these areas and present an impressive amount of material very succinctly, capitalizing on the book's many references. Again, projects are used to enhance the learning experience. The application areas in chapter 6 bring to mind *Structure from Motion in the Geosciences*, by Jonathan L. Carrivick, Mark W. Smith and Duncan J. Quincey, published in 2016 by Wiley-Blackwell. This covers imagery rather than lidar, so geoscience students now have complementary texts to help them use geospatial data.

Overall, the book is well produced and pleasing to use. With few exceptions, the illustrations are large enough and color is used where necessary. Nevertheless, a little more sub-editorial attention would have been propitious. The pages numbers for the data sets show up as "xx" on the location map on page ix. There are a few minor errors, such as σ^2 rather than σ for standard deviation (page 22) and two identical captions for two different figures (page 68). The use of colloquialisms such as "cookie cutter", "gold standard" and "wall-to-wall" may not be best for non-US readers.

Provided purchasers bear in mind that *LiDAR Remote Sensing and Applications* is focused on applications rather than lidar technology *per se*, the book is a useful and moderately priced contribution for undergraduate and graduate students new to lidar. The authors have done well to present so much material in only 200 pages. Certainly, some sections are little more than glimpses of application areas, but the fast moving, easily understood narrative and copious references encourage deeper study. Readers can maximize the book's didactic efficacy by downloading the data and stepping through the projects—this is certain to help in absorbing the material. The authors' assumption that readers will have access to and some familiarity with ArcGIS is a reasonable one in today's university environment.

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.

Bluesky Esri UK Partnership to Support Roll-Out of 5G and Full Fibre Networks

LEICESTERSHIRE, UK—Aerial mapping company Bluesky and Esri, the global leader in spatial analytics, have come together to offer a range of software, services and data to help telecoms companies roll-out the next generation of mobile and broadband services. A package of ArcGIS software, Esri UK services and high resolution aerial photography and data from Bluesky, will help the industry design and plan 5G and fibre-to-the-premise (FTTP) networks more quickly and cost effectively.

"Demand for wireless coverage and faster broadband connectivity is increasing exponentially in the UK and telecoms companies are investing billions of pounds in the installation of new wireless and fibre communication networks," commented James Harvey, Partner and Alliances Manager, Esri UK. "By partnering with Bluesky for the provision of the most up-to-date and accurate geographic data we can help the industry make informed decisions, improving service levels and achieving cost savings."

"As the telecoms industry moves into a new phase it is critical that it can identify and understand the opportunities and threats presented by the natural and built environment," added Rachel Tidmarsh, Managing Director Bluesky of International. "The use of powerful spatial analytics, as offered by ArcGIS, to support marketing, engineering and service delivery will continue to improve performance for consumers and offer a substantial return on investment for operators."

By using ArcGIS to analyse existing network data, alongside high resolution aerial imagery, height models and other datasets such as the National Tree Map from Bluesky, telecoms companies can easily identity prime sites for new masts and the optimal routes for fibre cables.

The powerful combination of spatial data analytics technology and highly accurate and up-to-date representations of topography, land use and land cover, allow network planners to take into consideration the location and height of potential obstacles such as building, trees and street furniture. Prime mast locations can be determined and fibre infrastructure investments prioritised with fewer site visits; saving time, reducing CO2 emissions and creating substantial cost savings.

Wireless network operators can also undertake ArcGIS analysis with the Bluesky data to identify other issues that may impact mobile signal strength, such as stone buildings and trees near masts. This deeper insight into the spatial context of a mobile network can be used to inform decisions relating to signal strength potentially improving the service for mobile phone users.

Bluesky is a specialist in aerial survey including aerial photography, LiDAR and thermal data, using the very latest survey technology, including two UltraCam Eagles and a Teledyne Optech Galaxy LiDAR system integrated with a PhaseOne camera and thermal sensor. An internationally recognised leader with projects extending around the globe, Bluesky is proud to work with prestigious organisations such as Google, the BBC and Government Agencies.

Fusion of Sensor Data Advances Geospatial Technology

With Trimble's next generation mobile mapping system, all sensors are time synchronized with precise GPS time tags and are linked to the trajectory that is recorded with the GNSS/IMU subsystem. That way, all recorded points and images can be properly aligned in a post-processing step.

The steady climb up the slope of improving sensor technology is generating better geospatial solutions, especially in mobile mapping and machine control, and as a result, improving workflows, productivity and project outcomes.

What is most exciting about data collection right now is the potential to bring together multiple different sensor types or technologies to advance geospatial solutions in the areas of cost, performance, availability and reliability.

For users of LiDAR and other single-sensor collection technologies, the combinations of data from different types of sensors into one solution can generate more useful data from missions, which can improve productivity and expand services.

In this way, what is most exciting also poses the greatest challenges for engineers and product developers who need to create hardware and software solutions that integrate multiple types of data to generate results users can rely on.

BY SHAWN **WEISENBURGER**

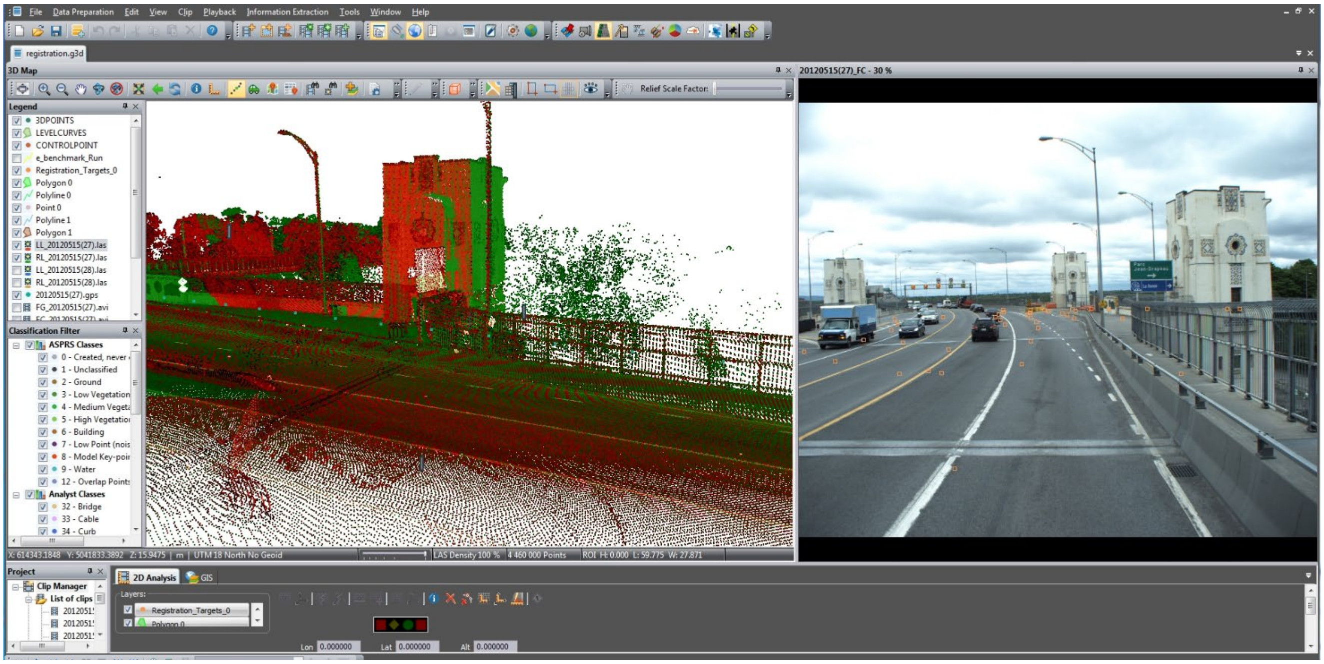
The Trimble MX7, equipped with six 5-megapixel cameras and Trimble Applanix GNSS and inertial geo-referencing modules, allows users to visually observe and capture the job site, then produce deliverables in the office later.

While not necessarily something users are demanding (yet), this sensor fusion is one of the leading edges of product development because of the power that comes from combining multiple different sensor types or technologies in ways that maximize their combined strengths while minimizing their combined weaknesses.

Under this backdrop, it's helpful to consider the technology and market trends driving the convergence of data from various and different types of sensors—whether inertial measurement unit (IMU), camera, barometer, Global Navigation Satellite System (GNSS), or Light Detection and Ranging (LiDAR)—and the software that will process the data from those disparate sources to deliver a continuous and unified stream of information.

Market motivation

For the geospatial market, there are multiple goals in maximizing the benefits of sensor fusion, including reducing costs, improving performance to get better positions or availability of positions, and increasing reliability and robustness. Geospatial technologists are finding new ways to fuse the data from diverse sensors

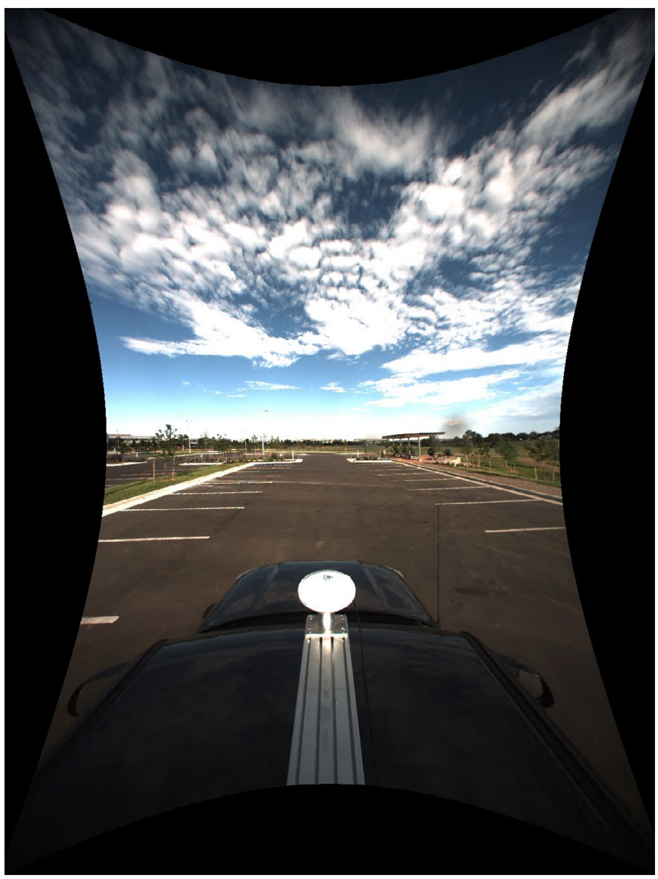


in an effort to make positioning with centimeter accuracy possible in any location and environment, such as enabling a GNSS user to walk indoors and maintain a high level of accuracy in data collection or walk into a forested area and maintain sub-meter or centimeter accuracy despite interruptions in line of sight to satellites.

Increased computing power and advancements in GNSS have improved the performance of geospatial solutions, but to continue to get better, technology needs to make greater use of existing sensors and also incorporate additional sensors for new sources of data.

As one example, consider that when data generated from an IMU (inertial measurement unit) and GNSS are integrated, the system gains the dependability and consistent accuracy of GNSS with the continuous data propagation of the IMU, which is useful in environments such as an urban canyon where GNSS signals can be interrupted.

Trimble Trident software can be used for image inspection and point cloud classification.



Undistorted imagery from Trimble MX2

The MX7 camera head enables 360 degree geo-referenced image collection.

Trimble Mobile Imaging software is used during an MX7/MX9 data collection campaign.

Autonomous vehicle technology sparks sensor innovation

The autonomous vehicle push has brought additional attention to geospatial solutions because of the need for multiple sensors beyond GNSS, including LiDAR and cameras. A driverless car in the same environment as vehicles operated by drivers can't rely on GNSS alone because that system won't work in certain conditions, such as tunnels, and can't pick up unexpected hazards, such as pedestrians walking on the street.

To work at all times, the driverless system needs multiple sensors. Improved vision and depth-sensing solutions are among the leading-edge technologies being used in the autonomous vehicle sector to compliment GNSS.

Inertial sensor technology gets smaller, better, less costly

At the same time, some sensors, such as the IMU, are now getting smaller and much less expensive.

The IMU is an electronic device that uses a combination of sensors—accelerometers, gyroscopes and sometimes magnetometers. An IMU measures specific force in three directions (forward/backward, left/right and up/down), as well as angular rate on three different axes. These measurements can be used to compute the body translation and orientation change over time.

Until fairly recently, inertial systems have been expensive, large, power-consuming and heavy, qualities that made them acceptable for a train or an airplane but a poor choice for smaller, more typical applications, like vehicles.

Inertial sensors measure specific force (acceleration excluding gravitation, so zero during free-fall) and angular rate. These measurements indicate motion changes. This movement in space is interesting in some applications, but geospatial users want to know where things are, not just where they are relative to other things. Another strength of the IMU is high measurement rate, typically 50 to 2,000 times per second.

Recent improvements in IMUs, and the advancement of Micro Electrical Mechanical Systems (MEMS) in particular, have made the inertial systems smaller and more cost effective. One example is the smart phone, which includes tiny inertial sensors that cost only a few dollars. These sensors aren't quite the quality needed for geospatial solutions, but they are getting close.

When inertial sensors are combined with GNSS, the system is able to estimate both position and orientation, which are important for guidance and navigation.

While GNSS needs to be able to see the sky and the satellites, an IMU does not. The weakness of the IMU method is that it is not stable over time, so its ability to determine position drifts very quickly with time. GPS is almost the opposite. In the short term, GPS has a slow uptake rate, but over the long term, it doesn't drift.

Vision sensors create rich data

On its own, a camera is a rich source of information. But that data is also a disadvantage because of the large amount of processing it requires, and state-of-the-art systems are still not 100% reliable due to variable lighting conditions. For geospatial purposes, the camera needs to be integrated with a sensor that provides absolute scale, like GPS, inertial, laser, or additional cameras.

Computer vision, or structure from motion, is an increasingly strong focus of geospatial technology. Computer vision uses a camera to take a photo or video and calculates movement and rotation based on changes in consecutive frames. The problem with computer vision is that the scale isn't known, similar to how the size of a tree can't be determined from a photograph of that tree because the distance between the camera and tree is unknown.

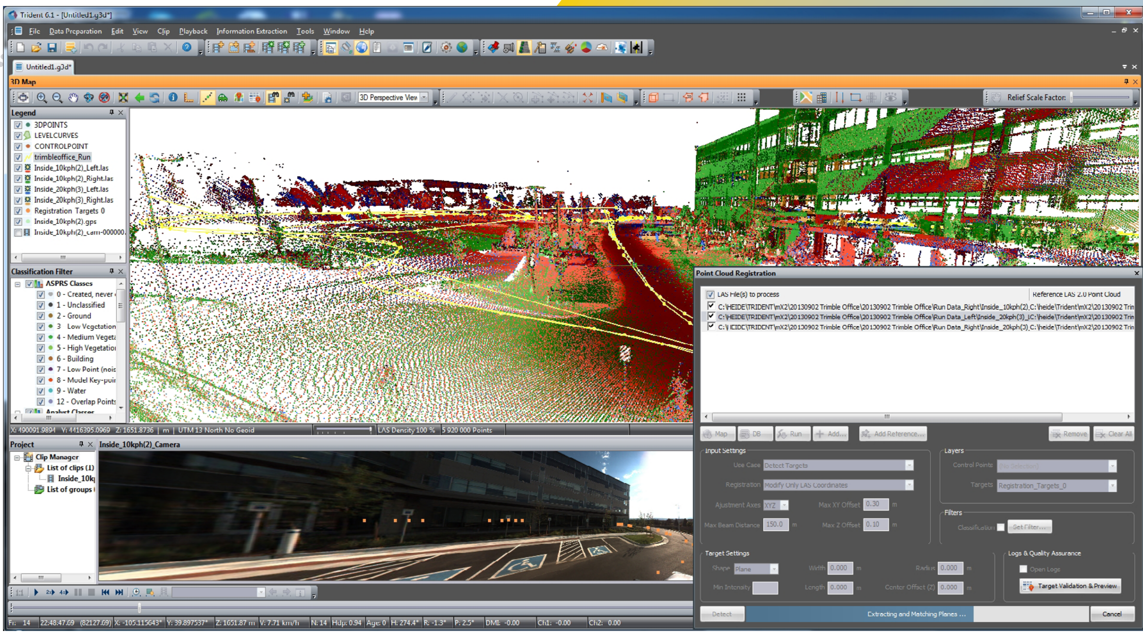
The Trimble Indoor Mobile Mapping Solution (TIMMS) fuses LiDAR, inertial, and spherical video for capturing spatial data of indoor and other GNSS denied areas.

On its own, computer vision can provide a model of the scene to an unknown scale, but a geospatial use requires integrating the vision sensors with GNSS or inertial to calculate absolute positions and position changes.

Mobile mapping combines sensors in powerful way

Mobile mapping systems exemplify the power of sensor data fusion by combining the various strengths and weaknesses of different types of sensors—inertial (IMU), wheel speed, GNSS, cameras and LiDAR—and fusing these sensor outputs into one large data set with many uses.

While a stand-alone, single-sensor solution will cost less than a



Trident software enables point clouds from multiple passes to be registered together to produce a single consistent point cloud.

multiple-sensor solution, the increased productivity gained from multiple sensors saves not only money, but time. Mobile mapping solutions allow efficient data acquisition over large areas from 10s to 100s of kilometers at highway speeds. In environments where safety might be an issue, such as an unclosed road, survey-grade data can be acquired without endangering ground crews. Such a system is particularly useful in transportation infrastructure planning, as-built surveying, GIS mapping and asset management.

Trimble's new MX9 mobile mapping system is one example. The MX9 combines multiple sensors, including two super-accurate high-density lasers that collect one million points per second, per laser, to generate survey-grade dense point cloud data. The lightweight system also combines a high-end Applanix GNSS IMU component and a spherical camera to get great images. All sensors are time synchronized with precise GPS time tags and are linked to the trajectory that is recorded with the GNSS/IMU subsystem. This way, all recorded points and images can be properly aligned in a post-processing step.

Processing sensor data

Sensor fusion is also about getting the most out of one data acquisition mission, and the more information collected, the greater the need for a smart system to handle it and avoid a data graveyard.

From a user's perspective, gathering data using a mobile mapping system is fairly straightforward, but once the data is collected users face the challenge of processing and analyzing the information.

The processing step is where the sensor fusion is needed. When GNSS is available it is an excellent source of absolute position, but because it requires line of sight to the satellites, there are many times when the positions are either degraded or completely unavailable due to obstructions. It also does not generally provide user orientation, which is required for mobile mapping. During these outages, sensor fusion becomes a requirement. By combining inertial, camera, LiDAR and odometer data, it is possible to maintain position and orientation during these inevitable outages. The quality of the fused solution depends on many factors, including the duration of the outage and the distance traveled.

Analysis of the data is the process of extracting information of interest. This generally involves detection and measurement and can range from fully automated analysis to a fully manual process. Common examples include detection and measurement of street furniture, road surface defects and curb mapping.

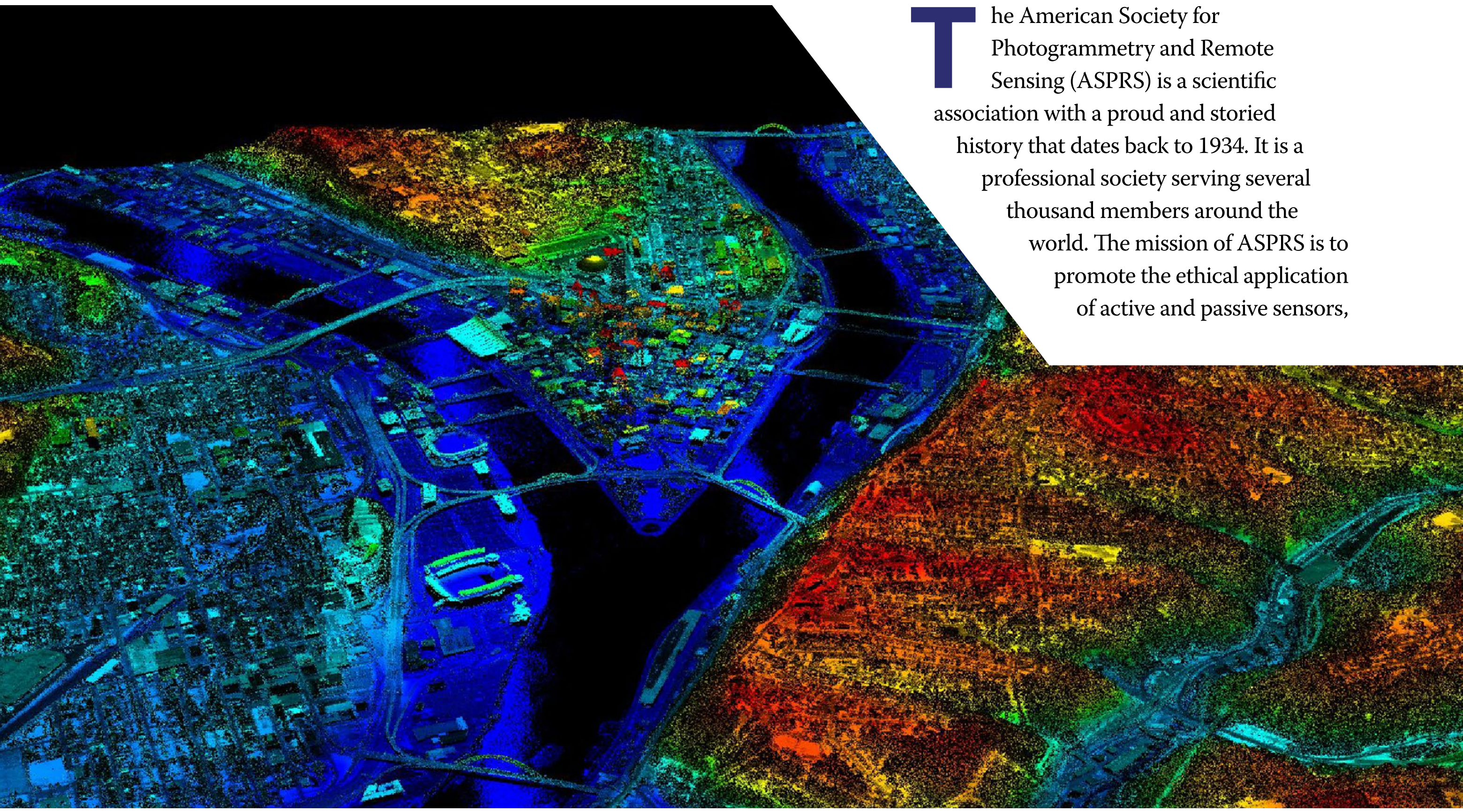
Having different types of sensor data can be extremely powerful, but even more beneficial is fusing that data into one analysis. The right software is critical to calibrate and co-register the data properly so it is presented in an accurate way. This means fusing the different sensor data sets, such as combining the individual points, or non-continuous data, from LiDAR, with the continuous data of edges and lines from cameras.

Supported by the right software, sensor fusion is about getting the most out of various sensors and sensor combinations to solve business problems.

Shawn Weisenburger is a Distinguished Engineer at Trimble Geospatial.

HOW ASPRS HELPS GUIDE THE LIDAR INDUSTRY

The American Society for Photogrammetry and Remote Sensing (ASPRS) is a scientific association with a proud and storied history that dates back to 1934. It is a professional society serving several thousand members around the world. The mission of ASPRS is to promote the ethical application of active and passive sensors,



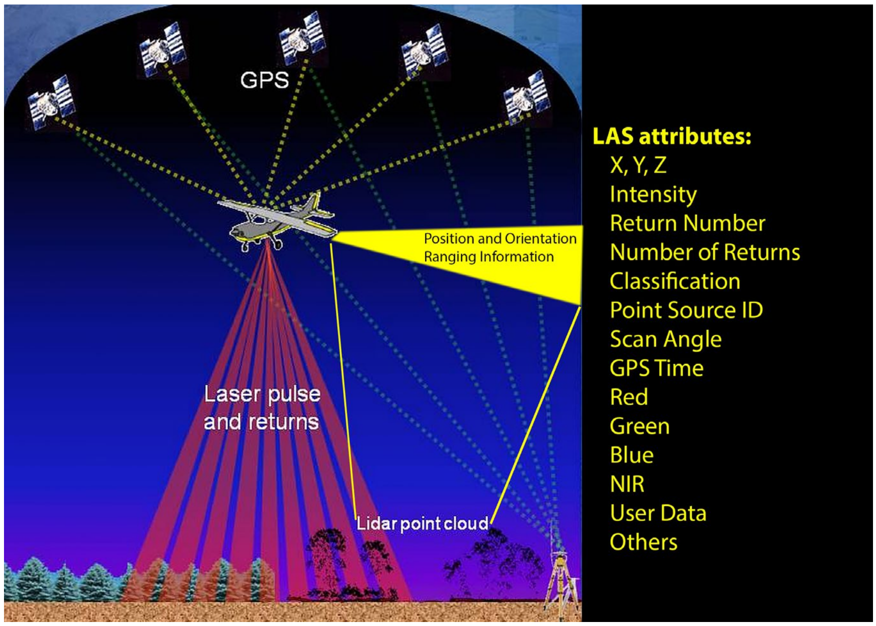
The LAS file format enables views and use of massive amounts of point cloud data across a wide range of software platforms. (Lidar over Pittsburgh, Pennsylvania)
Source: USGS

BY DR. JASON **STOKER**

the disciplines of photogrammetry, remote sensing, geographic information systems, and other supporting geospatial technologies; advance the understanding of the geospatial and related sciences; expand public awareness of the profession; and promote a balanced representation of the interests of government, academia, and private enterprise. ASPRS is organized to be responsive to the various types of remote sensing and mapping technologies, and currently has seven technical divisions: the GIS Division; the Lidar Division; the Photogrammetric Applications Division; the Primary Data Acquisition Division; the Professional Practice Division; the Remote Sensing Applications Division; and the Unmanned Autonomous Systems Division.

The Lidar Division was established by the ASPRS Board of Directors at its May 5, 2011 meeting in Milwaukee, Wisconsin. The Division is focused on all aspects of kinematic laser scanning (e.g. the entire sensing platform is in motion). The mission of the Division is to provide a forum for collection, development and dissemination of information related to the best practices in developing, maintaining and operating kinematic laser scanners and associated sensors. The Division currently comprises two committees and one working group:

- **Airborne Lidar Committee:** This committee develops best practices by soliciting input from the broad airborne laser scanning industry and from academia. Best practices are disseminated in both working papers and more formal specifications (such as the Vertical Accuracy Specification).



Source: USGS

Figure 1: Conversion of lidar instrument information into a LAS point cloud dataset. Information from laser pulses and their associated returns is combined with location (GNSS) and attitude (IMU) to create clouds of XYZ points (lower right).

- **Mobile Mapping Systems Committee:** This committee is a parallel committee to airborne but with the focus being land/water-based kinematic laser scanning systems.
- **LAS Working Group:** The LASer (LAS) Working Group maintains and updates the LAS kinematic laser data standard.

The role of ASPRS in standards

As part of its mission, ASPRS maintains a leadership role in the development of guidelines, standards, specifications and calibration processes for those sensors and activities of primary importance to the membership. The ASPRS Board of Directors has the responsibility for ASPRS standards and has chartered the ASPRS Standards Committee to oversee the ASPRS Standards Program: the committee has defined responsibilities and procedures for developing, maintaining, and approving standards authored by ASPRS. An ASPRS standard is one developed wholly by ASPRS for use by the geospatial community and ASPRS members. It is a goal of the ASPRS Standards Program to ensure the broadest acceptance and implementation of ASPRS standards within the geospatial community of interest by working with recognized Standards Development Organizations (SDOs) and Standards Setting Organizations (SSOs) to move ASPRS standards forward for further SDO and/or SSO processing.

Drawn from government, academia and the private sector together, members of ASPRS create not only standards, but best practices and guidelines that are shared throughout the community. This community approach

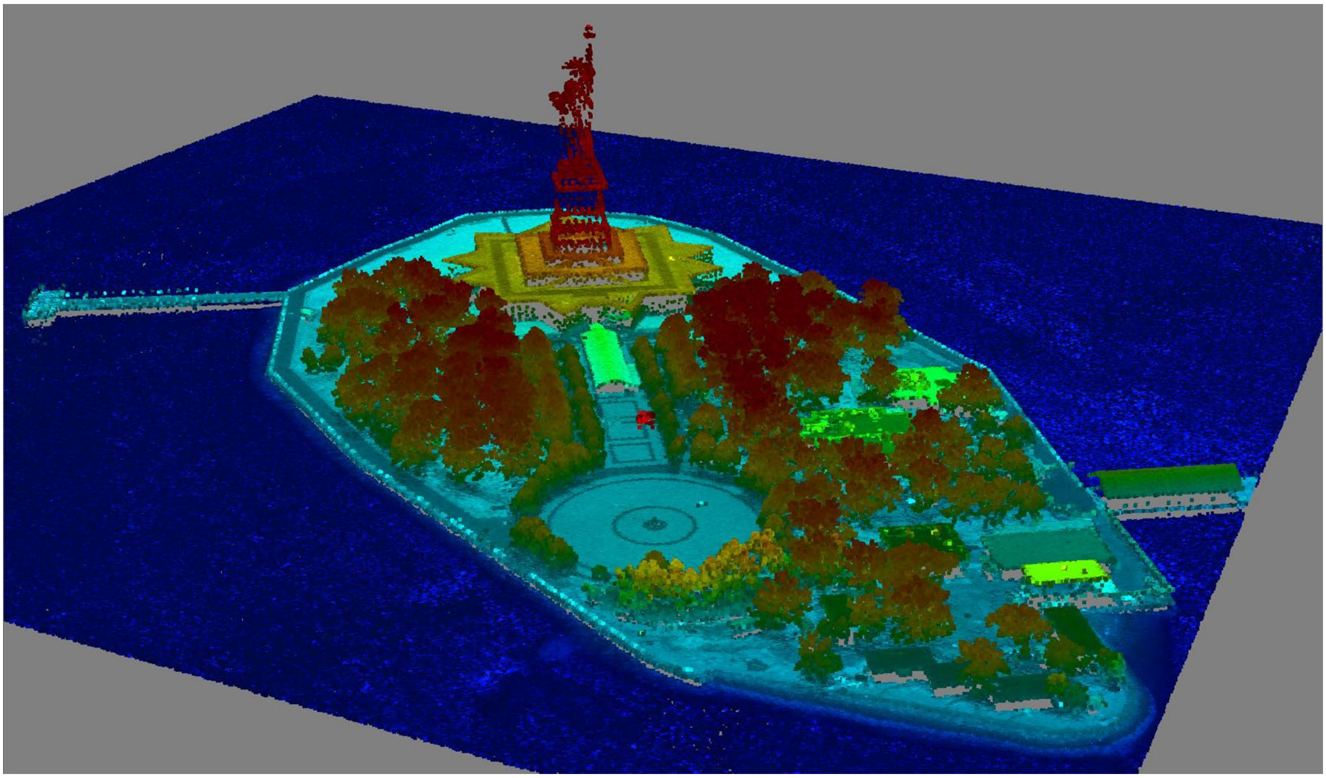


Figure 2: Calibration is critical when combining swaths of data to image objects such as the Statue of Liberty.

helps hardware manufacturers, software developers and end users to develop tools, methods and standard processes that move the industry forward in many beneficial ways. Working through ASPRS allows people to link proprietary and open source methods together, to the benefit of the end user and the community at large.

Standards developed by ASPRS are based on an open, consensus process. The Board of Directors is responsible for ensuring that all applicable requirements, including due process and consensus, have been met. Consensus is established when, in the judgment of the ASPRS Board, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

As it relates to the Lidar Division, two efforts have had immense impact on the industry. These are the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* and the *LAS Common Data Exchange Format Activity.* For example, both of these efforts helped the U.S. Geological Survey (USGS) develop its Lidar Base Specification, a document that dictates how data needs to be delivered to the USGS in order to be part of the 3D Elevation Program (3DEP). Accuracy information correlates with how the ASPRS has defined many aspects of accuracy and a fully populated LAS 1.4 file is now a required deliverable to 3DEP.

The LAS file format is a public file format for the interchange of three-dimensional point cloud data between data users. Although developed primarily for exchange of lidar point cloud data, this format supports the exchange of any three-dimensional x,y,z tuplet. This binary file format is an alternative to proprietary systems or a generic ASCII file interchange system used by many companies. One issue with proprietary systems is that data cannot always be easily taken from one system to another. There are two major problems with ASCII file interchange. The first is performance, because the reading and interpretation of ASCII elevation data can be very slow and

NEW
ScanLook TreX
Trimble
LiDAR USA
SNOOPY SERIES
256-274-1616
LiDAR USA
sales@lidarusa.com
Fagerman Technologies Inc.
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)

the file size can be extremely large, even for small amounts of data. The second problem is that all information specific to lidar data, such as instrument configurations and designs, is lost. The LAS file format is a binary file format that maintains information specific to the lidar nature of the data while not being overly complex (**Figure 1**).

The LAS file format was originally published on May 9, 2003, and has become the *de facto* standard file format for airborne lidar. LAS has also been widely used for other 3D point cloud data, including point clouds generated from photogrammetry, ground-based lidar, and structure-from-motion processing of imagery acquired from UAVs. There have been several revisions to LAS over the years. LAS 1.1 was published on May 7, 2005[1]; LAS 1.2, September 2, 2008[2]; LAS 1.3, October 24, 2010[3]; and LAS 1.4 was approved in November 2011[4]. LAS 1.4, the most recent approved version of the document, was also approved by the Open Geospatial Consortium (OGC) as a community standard in 2017. In July 2013, the Lidar Division created the ability to customize the LAS file format to meet application-specific needs. The mechanism that makes this possible is the LAS Domain Profile, which is a derivative of the base LAS v1.4 specification that adds (but does not remove or alter existing) point classes and attributes. For example the Topo-Bathy Lidar Domain Profile[5] adds point classification values for bathymetric point (e.g., seafloor or riverbed; also known as submerged topography), water surface, derived water surface, submerged object, IHO S-57 object, and bottom-not-found depth data. Extra Byte Variable Length Records (EXTRA_BYTES or Extra Byte VLRs) are added for pseudo-reflectance, uncertainty, water column depth, figure of merit, and processing specific flags[6]. We anticipate the release of additional domain profiles in the future; proposed additional domain profiles should be provided utilizing the LAS Domain Profile Description Template.

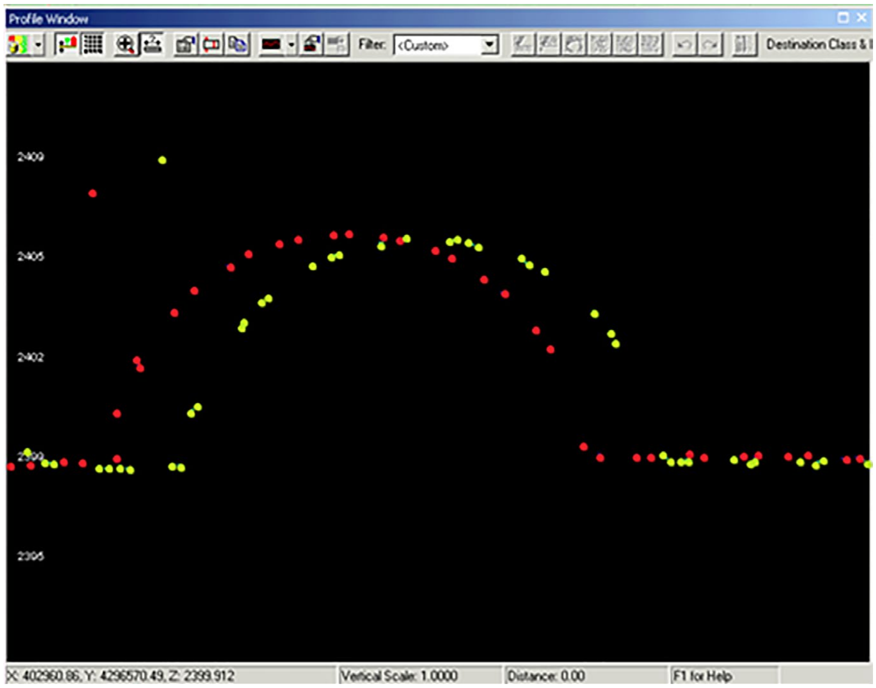


Figure 3: An example of misalignment between swath 1 (red) and swath 2 (green).
Image courtesy of Dr. Aparajithan Sampath, Stinger Ghaffarian Technologies, Inc. (SGT), contractor to USGS

New ASPRS Research and Development Topics for Assuring Geometric Quality of Lidar Data

The new ASPRS *Guidelines on Inter-Swath Geometric Accuracy of Lidar Data* and *Summary of Research and Development Efforts Necessary for Assuring Geometric Quality of Lidar Data* guides were developed through collaboration between the private sector and government partners via a USGS/ASPRS Lidar Data Quality Working Group (WG), sometimes referred to as the "ASPRS Lidar Cal/Val Working Group". Operating under the aegis of the ASPRS Lidar Division and its Airborne Lidar Committee, this group has investigated various factors associated with the geometric quality of lidar data. The WG has noted that while the quality of lidar data has improved tremendously in the past few years, the quality assurance and quality control (QA/QC) of data are not standardized, including the semantics, processes for measurement and reporting, and metadata. Therefore, to ensure geometric quality of lidar data that is required for scientific (statistical error propagation and estimation) and non-scientific purposes (including legal) (**Figure 2**), the WG has recommended several topics for research and development in a Summary document. In addition, the WG created guidelines on quantifying the relative horizontal and vertical errors observed between conjugate features in the overlapping regions of lidar data. The effort has been supported by the USGS National Geospatial Program (NGP) and the Land Remote Sensing (LRS) program.

Current specifications are not adequately able to quantify geometric errors (particularly horizontal and systematic geometric errors). This is mostly because the methods to quantify systematic and non-systematic errors have not been investigated sufficiently. Measuring only vertical accuracy also potentially underestimates the inter-swath errors, including the presence of systematic errors in lidar data (**Figure 3**). Hence they pose a risk to the user in terms of data acceptance (i.e. a higher potential for accepting potentially unsuitable data). For example, if the swath's overlap area is too small or if the sampled locations are close to the center of overlap, or if the errors are sampled in flat regions when there are residual horizontal errors in the data, the resultant Root Mean Square Differences (RMSD) can still be small. To avoid this, the following are suggested to be used as criteria for defining the inter-swath quality of data:

A. Median Discrepancy Angle
B. Mean and RMSD of Horizontal Errors derived from measurements on sloping surfaces
C. RMSD for uniformly sampled locations from flat areas to define vertical errors (defined as areas with less than 10 degrees of slope)

The recommendations are a result of discussions within the WG as well as the results of testing on sample datasets.

Associated Software

The recommendation from the WG was to implement the process defined in the guidelines in the form of software and test it on several datasets. The software was tested on datasets including swath data from both historical and recent projects available from 3DEP. The software was designed by the USGS's Earth Resources Observation and Science (EROS) Center and is currently being tested for implementation under operational QC conditions of the USGS's National Geospatial Technical Operations Center (NGTOC). The software and documentation can be downloaded from https://edcftp.cr.usgs.gov/project/rst/DQM/. The contents are:

- DQManage.exe and DQMeasure.exe: executables that need to be stored in same folder
- DQMAnalysisFun_Horizontal.py and DQMOutputAnalysisHorizontal.py: python scripts that should be in the same location
- LidarInterswath_CleanCopyASPRS.docx: explains the theory and motivation behind the DQM algorithms
- LidarResearchGuidelines_CleanCopyASPRS.docx: explains further work that needs to be done for ensuring lidar data quality
- DQMDocumentation.docx: help document for use of the programs
- DQM_Operational_Testing 2017-2-7.pptx: PowerPoint presentation made at ILMF 2017 on DQM implementation.

The software and documentation have been provided to ASPRS and will be managed by ASPRS Lidar Division and Standards Committee with support from USGS.

Conclusions

Since its inception in 1934, ASPRS has helped guide the photogrammetric, GIS and remote sensing industries into the future. As new technologies such as lidar mature and develop, ASPRS will continue to be a critical organization that bridges government, academia and private sector developments with a cohesive set of guidelines, best practices and standards. The LAS file format has helped increase the adoption of lidar data across an amazing array of sectors in the industry by standardizing a file format used across many software platforms. The Lidar Division of ASPRS looks forward to continuing to help guide the industry in ways that enable improved data collection, dissemination quality. Tools such as *Guidelines on the Inter-Swath Geometric Accuracy of Lidar Data* will help improve the accuracy and precision of lidar data into the future, a key contribution in our ever growing 3D mapping and place-based location and intelligence world.

[1] asprs.org/wp-content/uploads/2010/12/asprs_las_format_v11.pdf

[2] asprs.org/wp-content/uploads/2010/12/asprs_las_format_v12.pdf

[3] asprs.org/wp-content/uploads/2010/12/LAS_1_3_r11.pdf

[4] asprs.org/wp-content/uploads/2010/12/LAS_1_4_r12.pdf

[5] asprs.org/wp-content/uploads/2010/12/LAS_Domain_Profile_Description_Topo-Bathy_Lidar.pdf

[6] asprs.org/wp-content/uploads/2010/12/LAS_Domain_Profile_Description_Template.docx

Dr. Jason Stoker is a US Geological Survey Physical Scientist and is the Chief Scientist for the USGS 3D Elevation Program. Jason is also the former Director of the ASPRS Lidar Division.

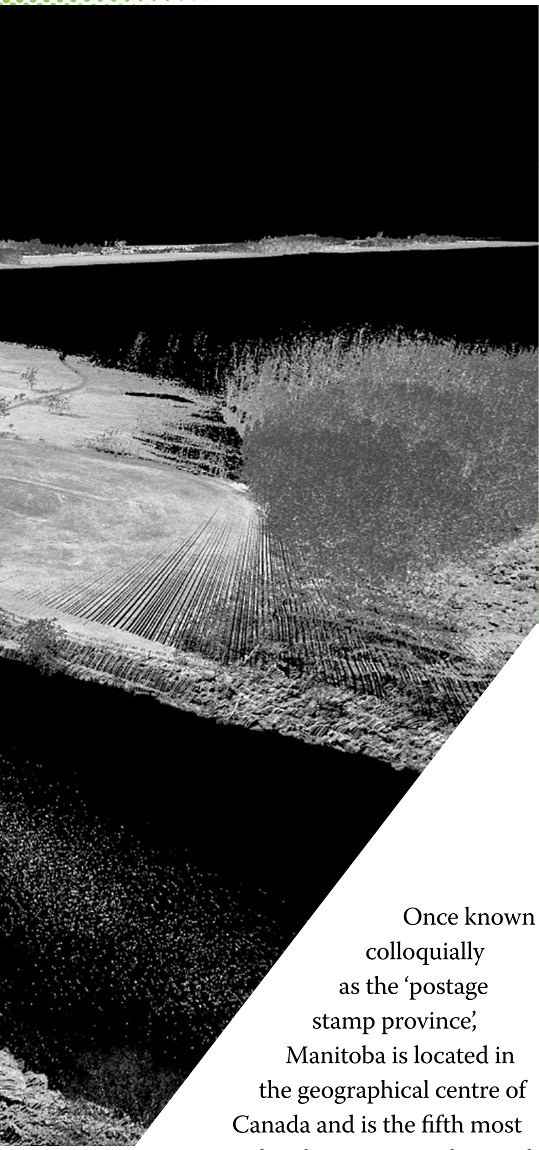
Point-cloud visualisation of a dam in Manitoba.

AIRBORNE LIDAR FLIES HIGH IN MANITOBA

The rising popularity of surveys using UAVs has led to great advances in photogrammetric techniques. Airborne lidar, however, still leads the way when it comes to collecting data across large geographical areas where elevation data is critical in places where foliage and vegetation can obstruct a standard camera's view. Madeleine Lake, lidar systems engineer at geospatial technology provider 3D Laser Mapping, based in Nottingham, UK, discusses how airborne lidar facilitated the successful mapping of varied terrain in Manitoba, Canada.

BY MADELEINE **LAKE**

The importance of Manitoba's highways cannot be overstated. 95 per cent of goods moved within the province depend on trucks and the trucking industry contributes more than $2 billion annually to Manitoba's GDP. Thus the upkeep and maintenance of the 19,000-kilometer provincial highway system is of paramount importance to the economy in Canada.



The ROBIN +WINGS mobile mapping system attached to a helicopter.

Once known colloquially as the 'postage stamp province', Manitoba is located in the geographical centre of Canada and is the fifth most populated province, with varied terrain that spans nearly 650,000 square kilometers. Manitoba is one of the three prairie provinces of Canada and its rural environment comprises mostly open grassland used to graze cattle and grow grain crops. The flat landscape, coupled with the high water levels, makes the area prone to devastating floods. In April 2017, several communities were severely affected by flood waters, leading to many of the area's highways being closed.

The geomorphology in Manitoba is complex for surveyors thanks to its glacial origins and the natural drainage of the ancient Lake Agassiz, which produced a flood of 150,000 km^3. This drainage is thought to have covered as much as 440,000 km^2 of Manitoba, Ontario, Minnesota, North Dakota and Saskatchewan.

One of the most important considerations for highway engineering, especially in high-risk flood areas, is the collection, transportation and disposal of water. Approximately a quarter of all highway construction money is spent on the creation of culverts, bridges and other drainage structures to help ensure roads don't become waterlogged and remain open for public use. Waterlogging can cause severe damage to road surfaces as well as prove costly in terms of disruption to services. With more than 110,000 lakes accounting for around 15 per cent of the province's surface, it's easy to see why hydrology is of high importance for those planning and maintaining critical infrastructure in Manitoba.

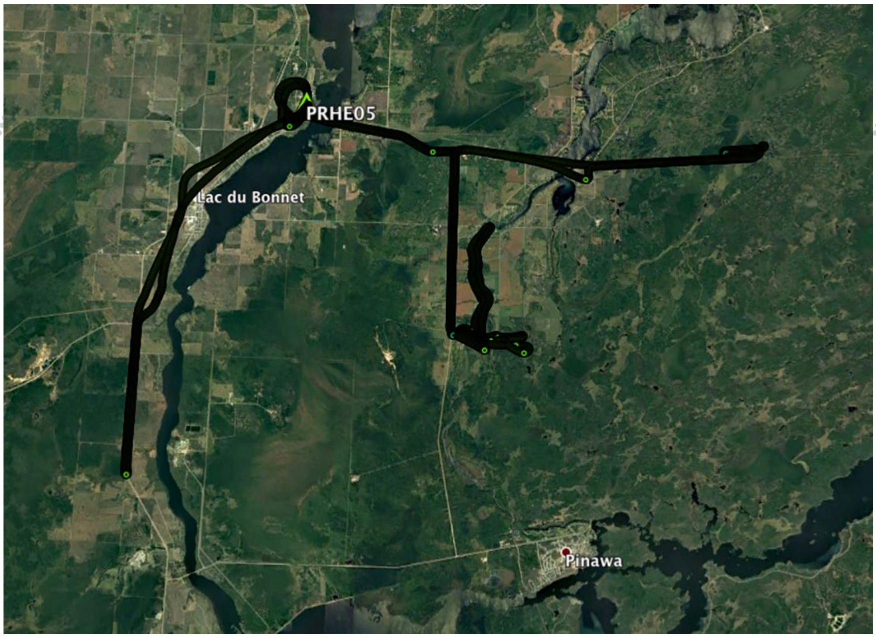
With this in mind, when Aquatics Environmental Services Inc. (Aquatics ESI), which specializes in collecting geospatial data in challenging environments, was tasked with surveying a flood-prone stretch of 100 km of Manitoban highway, it decided that an in-depth, progressive and cost-effective surveying method was required. Airborne lidar was the only logical solution.

By using a unique mobile mapping system, ROBIN, from 3D Laser Mapping, surveying teams can deploy different mounts depending on the applications and the survey environments. The backpack mount allows ground level surveys to be completed in areas which can be difficult to access, such as railway sidings and forests. It was the vehicle option, however, combined with the ability to mount the system on a helicopter, that appealed to the team at Aquatics ESI.

When installed on a manned helicopter, laser scanners allow operators and surveyors to gather highly detailed data sets from above, across a wide area. This level of unimpinged access is ideal where access to the site is limited, for example coastal areas and rural environments, and where accurate measurements are needed of complex infrastructure such as powerlines.

Aquatics ESI had previous experience of lidar technology, having carried out many hydrographic surveys using a combination of terrestrial laser scanning and sonar. Having been given a remit of covering a 200 m swath, detailing drainage ditches and culverts on either side of the highway, the survey team needed a system which could deliver high-resolution data in areas inaccessible on foot.

Rapid deployment and surveying speed were the most influential factors when it came to choosing survey equipment and sensors. The ability to deploy a helicopter ultimately saved time which would have been spent surveying the large area by other means. Nevertheless, the remit also required a certain point-cloud density to be collected, which would need to be facilitated by a vehicle-mounted system.



A map of the stretch of highway surveyed by 3D Laser Mapping.

The target of Aquatics ESI's survey was a stretch of highway close to the town of Lac du Bonnet, 115 km northeast of Winnipeg, on the west shore of the Winnipeg River (see map). Each year, officials struggle to maintain road networks such as this, which suffer from flooding, made worse by winter conditions below freezing, where culverts often become blocked with ice.

The Aquatics ESI survey team started by mounting ROBIN to a road vehicle. The highway was mapped in two passes whilst the road remained open to normal traffic. The team then moved to the nearby regional airport, where the system was transferred to a helicopter.

One of the major benefits of using airborne lidar is the speed at which data can be collected. The ROBIN +WINGS helipod facilitated a seamless transition from DRIVE mode into FLY, with the system connected directly into the helicopter's power supply, which enabled scans of extended duration to be carried


The ROBIN mobile mapping system in DRIVE mode.

ROBIN SYSTEM

Airborne lidar systems are traditionally only suitable for being mounted on to aircraft. ROBIN +WINGS takes the flexibility of the standard ROBIN system to new heights, with a simple-to-perform transition between WALK, DRIVE & FLY functions.

ROBIN +WINGS integrates the standard components of the ROBIN system with an extended capacity hard drive and control unit, which allows the system to be powered by the aircraft's power supply. The addition of three PhaseOne aerial cameras enables enhanced imagery to be collected to support the creation of high-density point clouds backed up by high-resolution georeferenced images.

The ROBIN system's flexibility means that data sets can be combined from WALK, DRIVE and FLY surveys, providing accurate and detailed information from both the ground and air.

The +WINGS add-on works with both single pole and nose helicopter mounts and can improve surveying results in a range of sectors, including forestry, environmental monitoring and transportation infrastructure mapping.

For more information about 3D Laser Mapping's ROBIN system, visit: *3dlasermapping.com/robin-mobile-mapping-system*

out. The same 100 km of highway was then remapped at an altitude of 100 m, at speeds of around 75-100 kph. Only two passes were needed, so the airborne scan was completed in less than 90 minutes.

The airborne data captured amounted to 20 GB of scanner data and 122 GB of raw image data, which was stored on the onboard datalogger for future processing and analysis. The ability to use ROBIN to scan the highway from the road as well as from above allows two datasets to be combined, providing the level of detail needed by planning and maintenance teams to assess weaknesses in the drainage systems.

When processed, the datasets from both the airborne and vehicle scans were matched together with an accuracy of between 1 and 2 cm. The noise on the roadbed was measured at 3 mm from a single drive pass and approximately 5 mm when the datasets were combined, without any control points in place.

Because both the helicopter and drive data had good absolute accuracy it was a straightforward task to merge the datasets. Since the drive data was the more accurate, this was used as reference data and the helicopter data was matched to it in height only (xy mismatch was minimal). This is an automatic process.

Airborne laser scanning offers an unrivalled perspective for mapping and surveying large or difficult-to-access locations and flexible, multi-use mobile mapping systems have become an invaluable tool for almost any type of survey.

The popularity of UAVs will continue to surge due to their ease of use and cost effectiveness. For large-area challenges, however, manned helicopters and light aircraft are needed and this is where multi-use mapping systems can show true value.

Madeleine Lake worked in Australia for three years as a geologist using geospatial datasets in a gold exploration and mining setting. Her MSc project used aerial LiDAR data for structural analysis of the Matano Fault in Sulawesi, Indonesia. Madeleine joined 3D Laser Mapping in February 2017 and is a technical member of the sales team.

3D LASER MAPPING

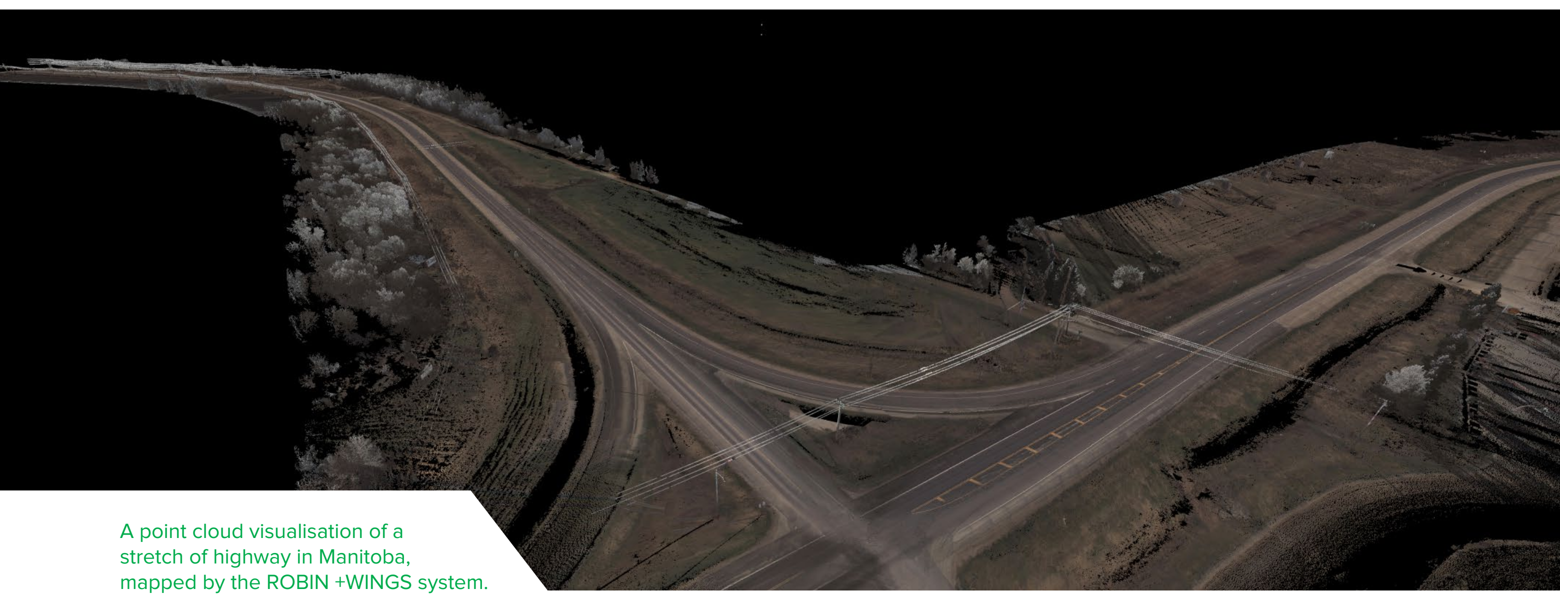
3D Laser Mapping is a world leading geospatial technology supplier and innovator. Underpinned by two decades of experience, the company provides 3D technology across the UK, South Africa, USA and Australia via its network of branch offices and international distributors.

Working alongside some of the world's biggest mining companies, governments, universities, blue-chip firms and operators of highways, power lines and railways, 3D Laser Mapping helps its customers to capture and understand their world in 3D.

The findings from mapping and monitoring are used to guide decision-making based on reliable, high quality measurements.

As well as providing cutting edge technology, technical support, training and consultancy services, 3D Laser Mapping's in-house research and development hub leads the way in product innovation.

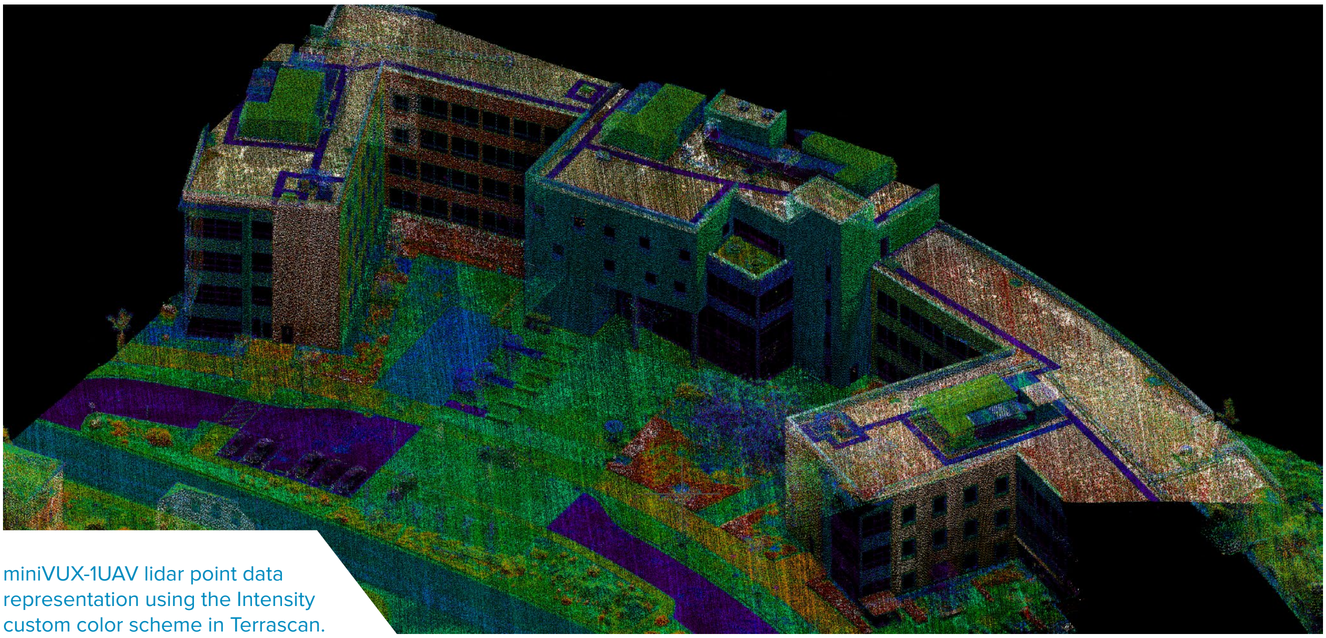
For more information, visit 3dlasermapping.com



A point cloud visualisation of a stretch of highway in Manitoba, mapped by the ROBIN +WINGS system.

The *RIEGL* miniVUX-1UAV

Charting the Evolution of *RIEGL* Sensors and Systems



miniVUX-1UAV lidar point data representation using the Intensity custom color scheme in Terrascan.
Provided by Jill Wrenn -PrecisionHawk

Over the last five decades, few can claim to have devoted more to the development of lidar technology than Dr. Johannes Riegl, founder and CEO of the *RIEGL* group. The miniVUX-1UAV is a recent example of his team's unique insight and ability. Prior to founding his namesake firm, Dr. Riegl focused on research and development work at the Vienna University of Technology from 1968-78. He started by developing high performance Avalanche Pulse Generators that are in principle still used in thousands of *RIEGL* instruments today for driving the semiconductor laser transmitter. In this article, I've opted to highlight some of *RIEGL's* key milestones and innovations that led to the development of the miniVUX-1UAV:

1975: Pulsed laser radar rangefinder Eumig LARA for hydrographic surveying applications.

1978: Worldwide first pulsed laser radar distance sensor for industrial applications.

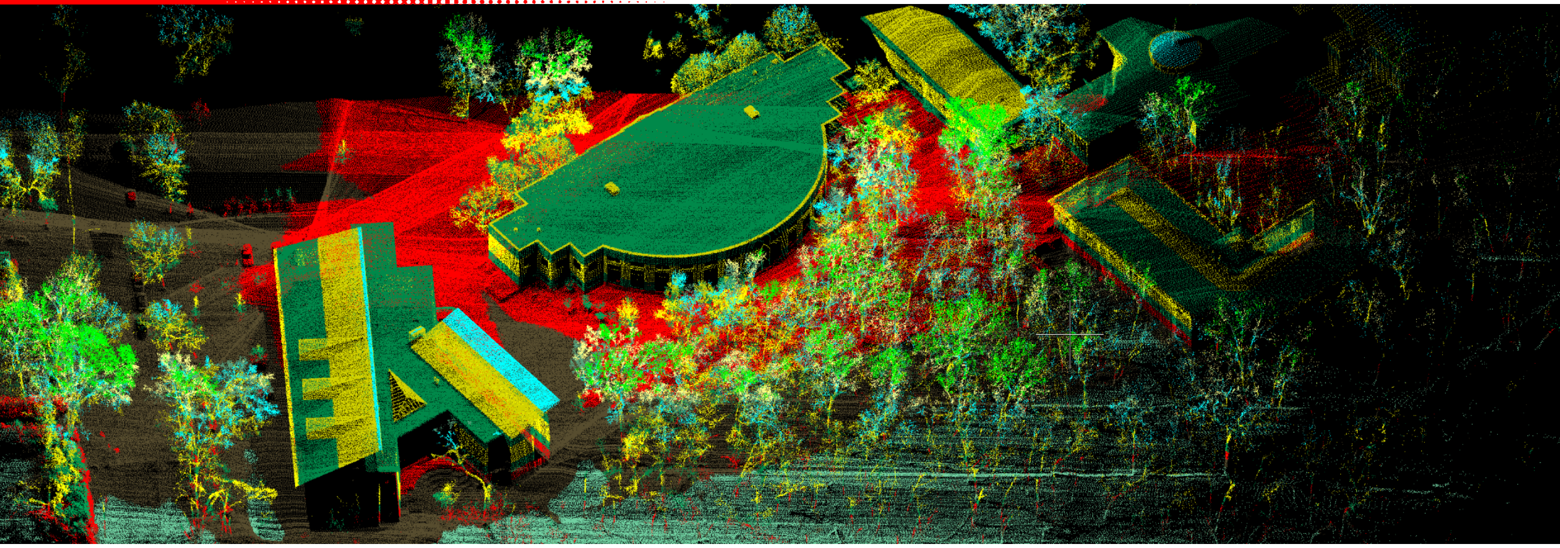
1979: Experimental setup of a pulsed semiconductor laser radar with digital echo signal processing.

1982: Laser Binoculars LR for hydrographic use.

1985: Development of an "add-on" rangefinder module for sniper use.

1986: LD90-2: industrial laser distance meter.

BY JAMES WILDER **YOUNG**



miniVUX-1UAV lidar point data representation using the Intensity custom color scheme in Terrascan.
Provided by Jill Wrenn -PrecisionHawk

1987: LD90-2-GF: First industrial laser distance meter with glass-fiber coupled optical head.

1989: LARA90-2; LR90-2: Next generation of "laser-binoculars" providing reduced size and upgraded performance.

1991: Lasertape: Worldwide first pocket sized "laser-binoculars" for non-professional use (hunting, sporting, etc.).

1992: Not everyone's darling: Laser "Speed Gun" for traffic law enforcement.

1993: LD-90-3: Next generation of distance and speed sensors for industrial use.

1995: LD90-3GF: Next generation of industrial distance and level sensors with glass-fiber coupled optical head.

1996: LASERTAPE FG21-HA: "Two in One" rangefinder & distance meter and *RIEGL*'s first Airborne Laser Scanner for corridor mapping

1997: ESA-Project "ASIS" (Active Surface Imaging System): definition, manufacturing, and testing of an advanced 3D laser sensor with a wide field of view (60 degree x 60 degree), first *RIEGL* "3D scanner" with rotating polygon mirror.

2000: LMS-Q140: improve airborne Laser scanner; ESA-Project "LRF" (Laser rangefinder for RV Sensor): development of a space qualified laser rangefinder for docking applications (ATV and HTV), manufacturing of engineering models, flown in April 2008.

2003: LMS-Q280: medium range airborne laser scanner and LMS Z420i High accuracy and long-range 3D laser imaging sensor.

2004: LPM-i800HA: high-accuracy and long-range laser profile measuring system; LMS -Q240: Airborne laser scanner, successor to LMS-Q140i; LMS-Q560: the world's first commercially available digitizing and Full Waveform processing airborne laser scanner.

2005: LMS-Q120: 2D laser scanner for industrial applications; LMS-Q160: Lightweight anti-collision sensor for UAV's.

2006: *RIEGL* BP560: Airborne laser scanner system, belly-pod mounted on diamond DA42 MPP twin engine plane.

2007: LPM-321: Extremely long-range 3D profile measuring system.

2008/2009: LMS-Z620: Very long-range 3D terrestrial laser scanner optimized for long-range topography and mining applications; LMS-Z210ii-S: Rugged 3D imaging sensor for industrial applications; VZ-400: The World's first online waveform processing 3D terrestrial laser scanner; LMS-Q680: World's first airborne laser scanner offering *RIEGL*'s unique MTA ("multiple-time-around") processing technology to benefit from the high laser pulse repetition rate (PRR) of up to 400kHz also from high flight altitudes, thus achieving up to 266,000 points on the ground per second.

2009/2010: *RIEGL* launches the VMX-250 Mobile Laser Scanning System at InterGEO—a compact, innovative high-performance platform for high-speed mobile 3D data acquisition reducing the complexity of integration, installation, and post processing to a minimum. The NP680i is unveiled, in cooperation with Diamond Aircraft Industries, *RIEGL* develops an innovative "turnkey' solution for surveying missions by directly integrating the LMS-Q680i airborne scanner into the "Universal Nose" of the twin-engine DA42 MPP. Later, the VZ-1000, a terrestrial scanner providing online waveform-processing for long range applications (1400m) is made available.

2011: VMX-450: With the VMX-450 Mobile Laser Scanning System, up to 1.1 million measurements and up to 400 scans are feasible per second in passing by. Using the optical camera system with up to 6 high resolution cameras, the records are complemented with time-stamped images; VZ-4000: Specially designed for applications in open pit mining and topography, the VZ-4000 provides a measurement range of up to 4,000 m sets new standards in terrestrial laser scanning.

2011/2012: VQ-820-G: Combined with new and innovative *RIEGL* software packages for calibration data acquisition and processing, *RIEGL*'s first hydrographic airborne laser scanner is excellently suited for combined land and hydrographic survey of coastlines and shallow waters. The software release included well-proven software for terrestrial, mobile and airborne solutions.

RIEGL launched RiPRECISION, RiSOLVE, and RiMTA offering completely new tasks.

LMS-Q780: This airborne laser scanner is the first one providing up to 10,000 feet flight altitude and up to 400kHz laser pulse repetition rate. Unique features of this instrument include the automated resolution of range ambiguities, typically occurring at large measurement ranges and high repetition rates.

2013: LMS-Q1560: Dual lidar Channel System: Ultra high performance, fully integrated and calibrated Airborne Mapping System for large scale, high altitude, complex environment mapping released in Vienna. VMX-450-Rail also released; a well proven, fully integrated high speed Mobile Laser Mapping System, optimized for railway applications.

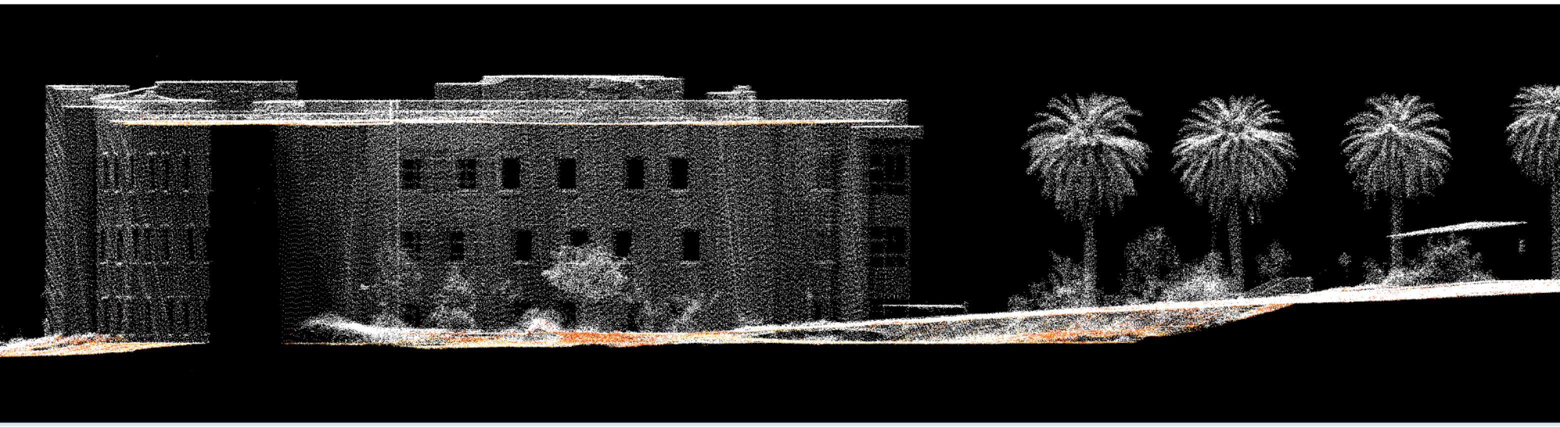
2014 -UAV lidar Scanners

2014: VUX-1: Marketed as the world's first airborne laser scanner meeting the challenges of emerging surveying solutions by UAS, UAV, gyrocopters, and ultra-light aircraft, both in measurement performance and in system integration.

2016: miniVUX-1UAV: A very compact miniaturized 360-degree field of view lidar sensor with only 1.6 kilograms and especially developed for the implementation of emerging survey solutions by small UAS/UAV/RPAS. The new sensor offers multi-target capability and accuracy using echo digitization and online waveform processing for data acquisition. The sensor is capable of 100,000 measurements per second and offers a measurement capacity of up to 250 meters. Its small size and very low weight make it well suited for mounting under limited weight and space conditions. The user friendly and cost-efficient device allows UAV based acquisition of survey grade data.

The *RIEGL* miniVUX-1UAV on the top and the Riegl miniVUX-1DL on the bottom.
Provided by Riegl USA.

2017: miniVUX-DL1: A sister device to the miniature UAV laser scanner miniVUX-1UAV. The added indicator "DL" means "downward looking" and refers to its special design tailored to meet the needs of corridor mapping tasks (downward looking, optimized field of view, small size). The DL is suited for tasks such as inspection, powerline and pipeline surveillance, or for infrastructure inspection as in highway



miniVUX-1UAV lidar point data representation colored by classification in Terrascan.
Provided by Jill Wrenn -PrecisionHawk

or railway monitoring. The wedge prism scanner construction produces a FOV of 46 degrees and the circular scan pattern provides a very high point density and good point distribution.

PrecisionHawk currently employs the miniVUX-1UAV within all the vertical markets we service, including but not limited to Agriculture, Government, Insurance, Energy and Construction. PrecisionHawk's servicing department picked the *RIEGL* miniVUX-1UAV because of the efficiencies it provides over other sensors. It can fly twice as high as other sensors in the same class and is supported by a premier suite of processing tools (software). It's important to state that the accuracy this sensor provides is both absolute and relative; the manufacturer's stated accuracy is 1.5cm absolute accuracy and 1.0cm in precision. The sensor provides up to 5 returns per pulse increasing the probability of reaching the ground significantly.

The main factor in selecting the *RIEGL* miniVUX-1UAV was the point repeatability and clarity of the data. It is well documented that *RIEGL* sensors are excellent at generating highly accurate, clean data sets. The data exceeded our expectations drastically and the point usability is significantly better than other sensors we've tried. What this means is more points that are generated from the miniVUX-1UAV can be used for the end-product as it relates to other drone lidar sensors. Typically, there is almost no noise in these data sets as compared to other drone lidar sensors that have significant noise. Although, the other manufactures market repetition rate and say how you can get 300,000 points per second or 600,000 points per second with a 2-return sensor versus the miniVUX-1UAV sensor at 100,000 points per second with 5 returns. The amount of noise in the associated data with the 300,000 to 600,000 points per meter sensor is significantly more than the miniVUX-1UAV. The associated noise is about 4 to 10 times in distance or say 4 to 10cm of noise versus the 1 cm of precision in the miniVUX-1UAV so that when you filter out the noise from the faster rep. rate sensor, the actual usable points are less that what is usable with the miniVUX-1UAV. An example of the accuracy for a project flown with the miniVUX-1UAV for one of PrecisionHawk's engineering clients yielded an accuracy of 1.34cm RMSE. This project was flown at 80m above ground level with 50 percent overlap and yielded roughly 80 to 100 points per meter.

The miniVUX-1UAV sensor can quickly pay for itself if utilized efficiently. You'll be hard pressed to find better accuracy, precision, reliability, ease of calibration and processing from other drone sensors. Celebrating their 40th anniversary in 2018, *RIEGL* continues to excel at developing outstanding equipment.

James Wilder Young (Jamie) CP, CMS-L, GISP is currently Director – Data/LiDAR Services for PrecisionHawk, headquartered in Raleigh, North Carolina, the leader in providing innovative information data using drones. He is currently supporting all aspects of LiDAR technology as it relates to drone technology. His experience includes all aspects of LiDAR including sensor development, applications development, data acquisition, data processing and project management. He graduated from The University of Colorado.

The latest technology, a Topcon GLS-2000 3D Laser Scanner, was used to capture the old Olivina Winery building's structural dimensions.

CAPTURING THE PAST

Historic Livermore winery building lives on in a 3D point cloud

BY JEFF WINKE

Livermore, California has a famous light...or more precisely, a lightbulb. For more than a century now the 4-watt light bulb, called the Centennial Light, has been burning since it was first clicked on in 1901. Housed in the Livermore-Pleasanton Fire Department Station #6, it glows dimly, but still functions as a light bulb.

The Livermore community has other historical phenomena of note, including a historic building on the grounds of the Sycamore Grove Park. Predating Livermore's historic lightbulb by about 15 years, the Olivina Winery building was constructed in 1885, which established one of the oldest wineries in the Livermore Valley. The Mediterranean-like climate—hot during the day and cool at night—is ideal for cultivating wine grapes and olive trees. Olivina pursued both businesses, thus the name, Olivina, coming from "olives" and "vines."

The Olivina winery building was unique because it is the first gravity fed winery in California. The founders cleverly built the four-story structure up against a hill so that freshly-harvested grapes could be loaded into the fourth-floor mashing room from up on top of the hill. Each floor below contributed to the wine-making process filtering out stems and reducing the pulp to liquid. The ground floor is where the juice was processed and loaded into kegs for final fermentation.

The hill not only provided the elevation for accessing the fourth floor, but was carved into to create an earth-cooled storage warehouse for the kegs filled with fermenting wine.

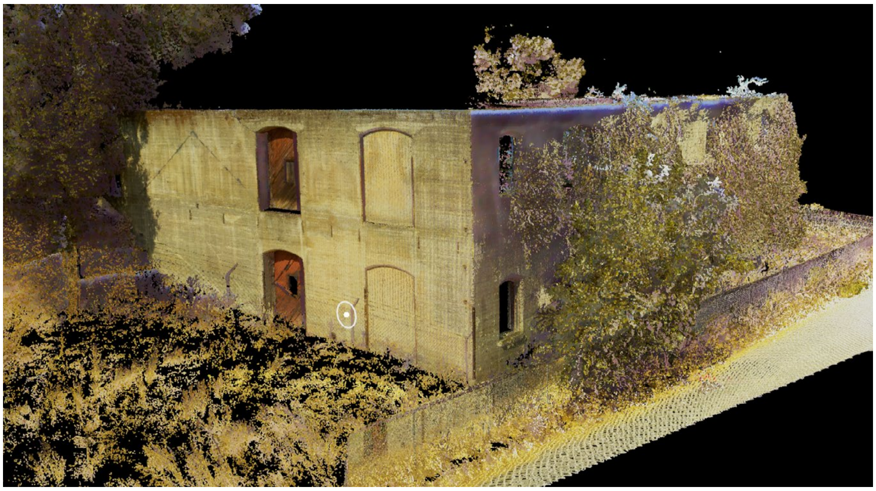
Olivina's wine production remained strong until the combination of fatal vineyard diseases, which were first occurring in Livermore vineyards just before the 20th century and Prohibition ceased production for good in 1920.

The winery remained vacant, once production stopped.

"The building was fun to play in when we were kids," said Charles T. Crohare, master miller at Olivina, LLC

A scan originating from a GLS-2000 has a single distance accuracy of +/-3.5mm. When taking the whole surface into account, a model can be created with millimeter accuracy.

The non-invasive approach taken with terrestrial scanning has allowed for a highly precise building exterior model to be captured.



MAGNET Collage Web allows for annotation notes, retracing, and measuring distances and areas on the model directly from a web browser.

The compact high-speed Topcon GLS-2000 3D Laser Scanner provides a full dome 360°(H) and 270°(V) field-of-view (FOV), enabling the capture of point cloud data of the building.

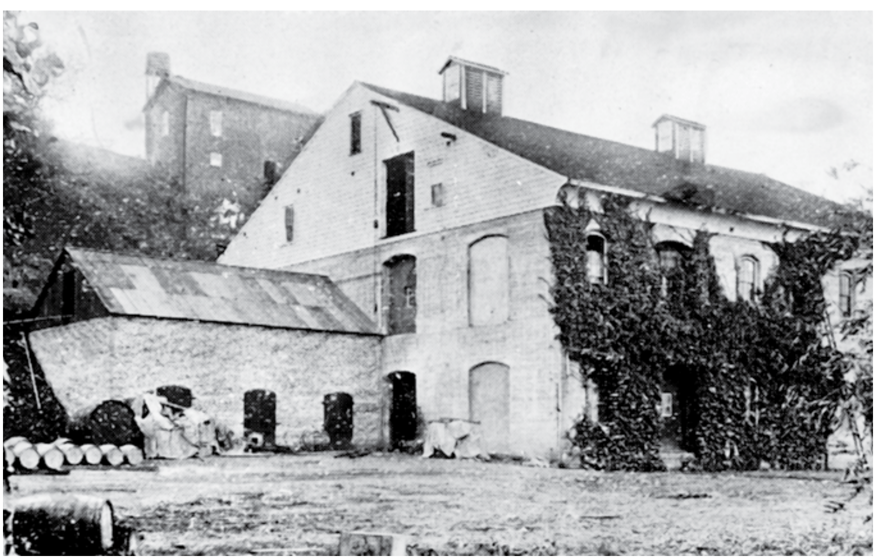
and fourth-generation-son of one of the founders. "I remember climbing the redwood steps to the top floor and exploring the building which was also a 'secret' make-out place for high-school kids, as evidenced by spray-painted hearts with the likes of Johnny Loves Susie there for all to know."

Through years of dormancy and neglect, the building has been deteriorating.

"In 1974 our family sold/donated 800 acres including the winery building to create the Sycamore Grove Park," Crohare stated. "We were happy to see the land conserved and protected."

The Olivina land fits squarely into a South Livermore Development Plan that city, county, community leaders, and area businesses have all contributed to. The plan calls for preserving open space, controlling commercial and residential development, providing conservation easements, and ensuring that the land can be enjoyed by the community in perpetuity.

"It's our understanding that the Olivina winery building is a future candidate for a historic restoration, museum, or community center," stated Ron Oberlander who is with Topcon Positioning Systems, which is headquartered in Livermore. "That's why we decided to donate our time, expertise, and resources to create thorough architectural documentation of the structure."



When in full production, the winery building was clearly a modest-looking production facility.

The project became a learning opportunity for a group of Topcon interns who were able to use the most current Topcon technology and software to perform a 3D point-cloud scan for historical preservation purposes. With 3D scanning technology, the intern team captured precise dimensions in a noninvasive manner—in other words, no one needed to pass beyond the safety fencing or go into the building.

Weeks earlier the ruin next door collapsed. The intern team felt good that the scans they were completing will keep the dimensional data of the historic winery building protected from any such events. The data set can be

All the data-collecting scans were completed safely outside the Olivina winery ruins grounds.

used for later analysis such as taking measurements, tracing over a building layout, and converting the building into a computer model.

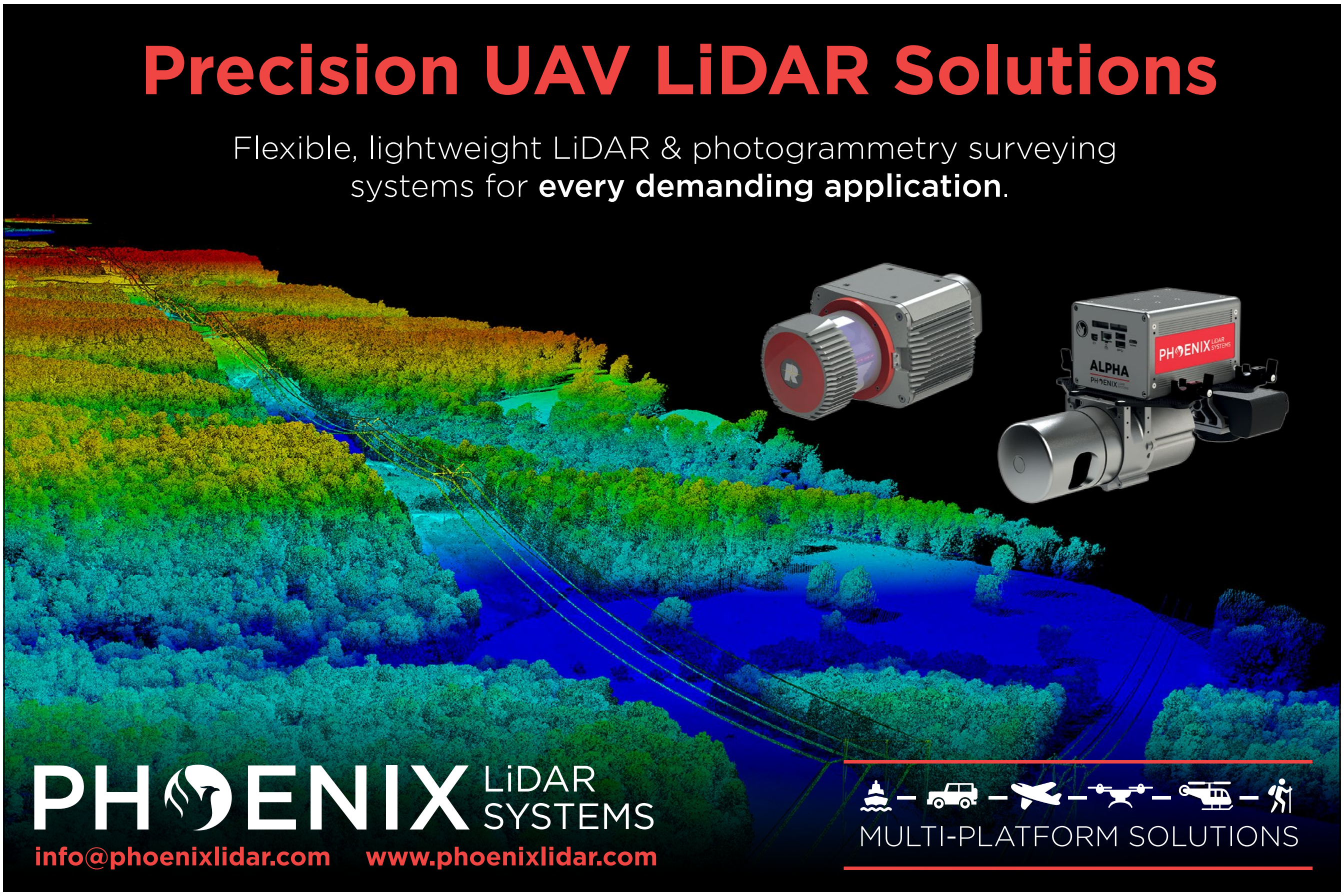
The intern team used a Topcon GLS-2000 3D Laser Scanner to capture the old Olivina Winery building's structural dimensions. The eye-safe laser has a 1,640 foot (500 m) range which meant it could safely be positioned outside the deteriorating building's cordoned-off safety parameter.

The Topcon device is said to provide survey-grade accuracy which reduces the number of scan settings and it features dual cameras designed to ensure the best definition.

Using newly launched MAGNET Collage Web software from Topcon, the intern team was able to take the 3D point clouds of the Olivina winery building it had recorded with the laser scanner and share them on the web. The integrated web service provides high-resolution point clouds of the winery building, which provides accurate distances, area measurements, and cross-sections that can be viewed, shared, or edited on the web.

"We're quite pleased with the results of the Olivina Winery building project on so many levels," said Oberlander. "Our interns had a meaningful project to further their learning, the Livermore Heritage Guild, which is a significant historical resource in the community, and the Crohare family now have definitive documentation of the winery building, and the park service and community has valuable data for a time when any restoration might take place. A definite win for all involved!"

Jeff Winke is a business and construction writer based in Milwaukee, Wis. He can be reached through jeff_winke@yahoo.com.

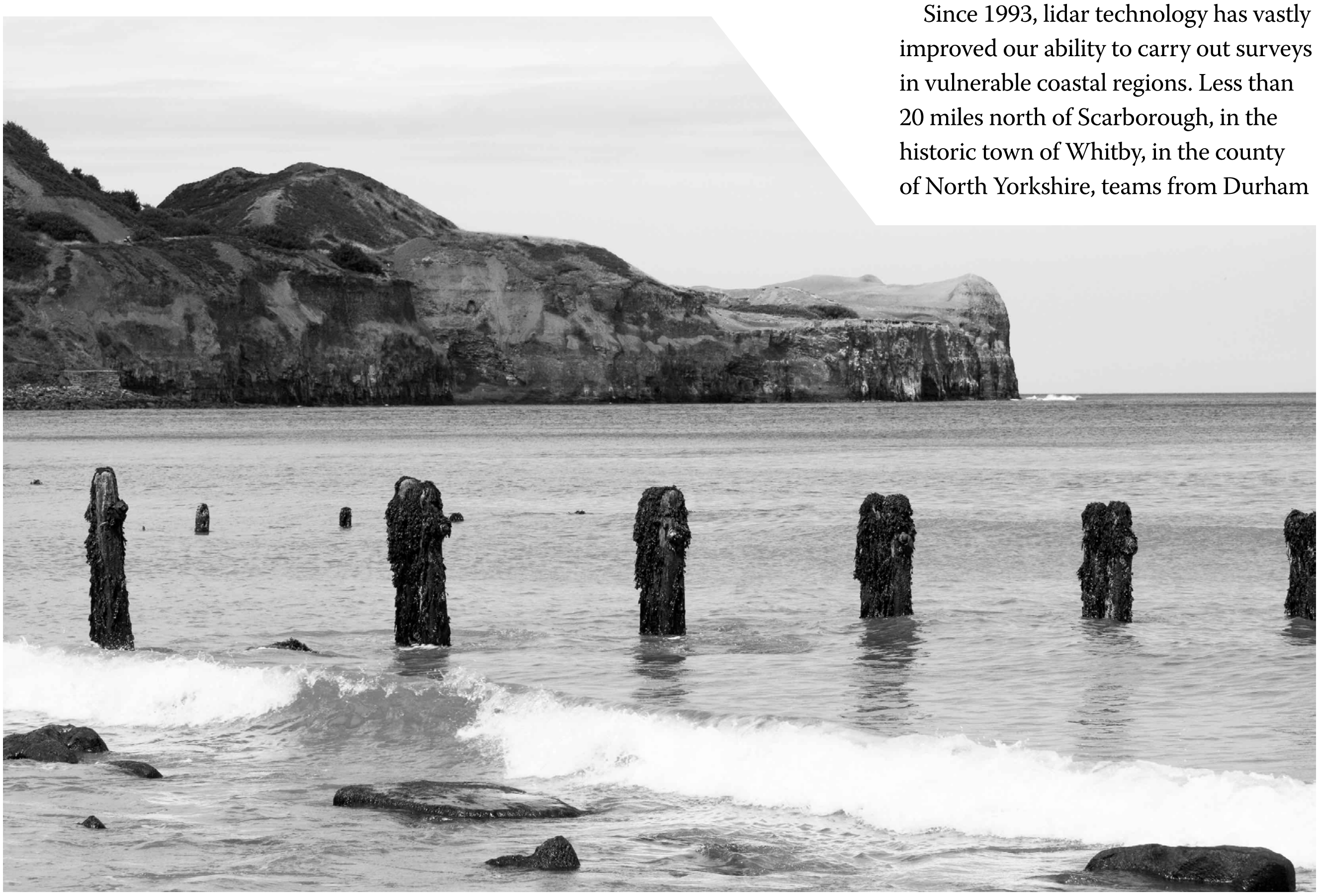

Precision UAV LiDAR Solutions
Flexible, lightweight LiDAR & photogrammetry surveying systems for every demanding application.
PHOENIX LiDAR SYSTEMS
info@phoenixlidar.com www.phoenixlidar.com
MULTI-PLATFORM SOLUTIONS


NEW
LeddarVu
SMALL, AFFORDABLE, LONG RANGE SOLID-STATE LIDAR
Very compact and lightweight - Range up to 215 m - No moving parts, for ultimate robustness
The perfect LiDAR solution for your application
▪ Vehicle collision avoidance
▪ Drones/UAS sense-and-avoid
▪ AGV/UGV Navigation
▪ Advanced Traffic Management Systems
▪ Occupancy sensing and surveillance
Available today. Learn more at
leddartech.com/leddarvu
LeddarTech®
MASTERING LIDAR SENSOR TECHNOLOGY

Coastal Monitoring Project Provides Blueprint for Future Surveys

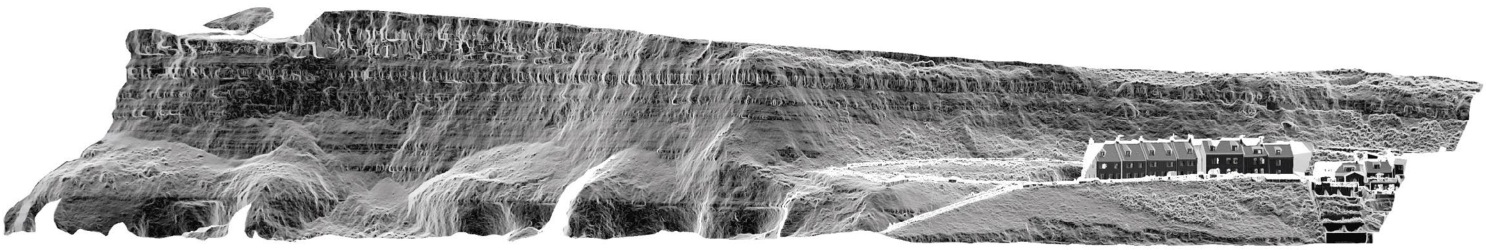
Though it happened almost 25 years ago, the dramatic collapse of Holbeck Hall Hotel in Scarborough, United Kingdom remains a pertinent reminder of just how unstable coastlines can be. In the weeks beforehand, cracks had been reported, but the subsequent landslide forced guests and staff to flee quickly before witnessing the entire building collapsing into the North Sea. Later, the British Geological Survey attributed this extraordinary event to a combination of heavy rainfall (140 mm in two months), drainage issues and water pressure.

Since 1993, lidar technology has vastly improved our ability to carry out surveys in vulnerable coastal regions. Less than 20 miles north of Scarborough, in the historic town of Whitby, in the county of North Yorkshire, teams from Durham



BY JOE **BEECHING**

ROBIN +WINGS Airborne LiDAR System



ALS point cloud of the Whitby coast

University and 3D Laser Mapping have been gathering data along a 23 km stretch of coastline since 2013, in order to establish the extent of erosion, slope instability and landslide risk.

As well as being home to nearly 605,000 people, North Yorkshire is one of the most popular tourist destinations in the UK. The sheer number of hotels, restaurants, shops and historic attractions in Whitby means that a natural disaster could have a devastating impact on human life, infrastructure and the economy.

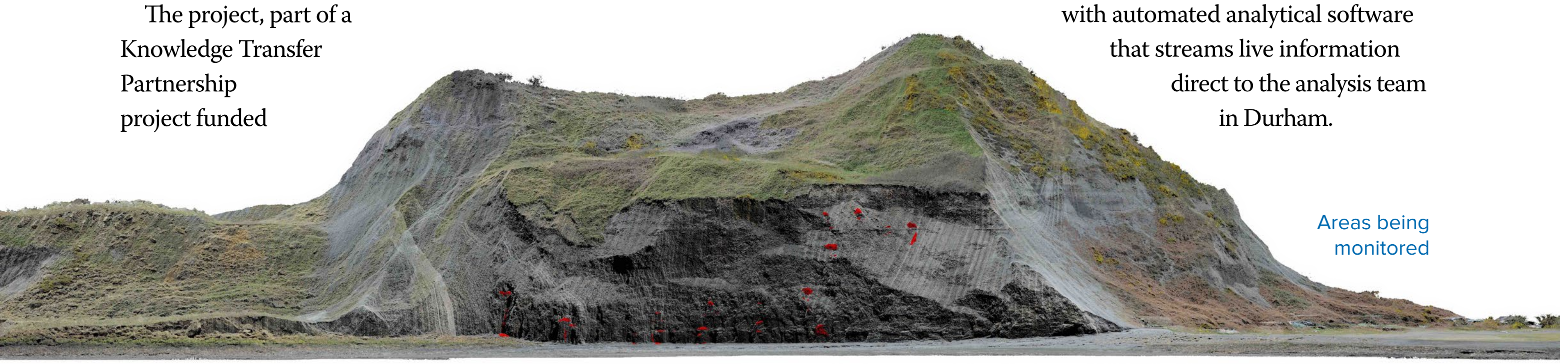
Of course, the challenges of working in coastal areas are well-known and this project was no exception. Much of the site, a mix of bare earth and heavily vegetated terrain, is inaccessible to survey teams working on foot because of major instability, including regular rockfalls and landslides.

The project, part of a Knowledge Transfer Partnership project funded by Innovate UK, aims to show how wave erosion at the base of the cliffs is undercutting the rock, resulting in land collapsing into the sea. Using a combination of airborne laser scanning, photography, terrestrial laser scanning, weather sensors and monitoring software, data is collected on a monthly and annual basis and then integrated to create highly detailed 3D models.

Given the challenging terrain and the fact that the area stretches 23 km along the coast, airborne surveys are conducted with the lightweight ROBIN +WINGS Mobile Mapping System from 3D Laser Mapping. This device was mounted onto a helicopter and, over a 10-month period, experts completed two surveys, creating a 3D map to show where changes had occurred.

Alongside the airborne device, Durham University chose the lidar-based SITEMONITOR LIVE solution, consisting of software and laser scanner, for regular and continuous data capture over 12 months. SITEMONITOR LIVE is a monitoring solution based on the use of a laser scanner and the software together. It allows for teams to manage the data generated from laser scanners across a whole site. This unique, scalable solution captures and manages 3D point-cloud data recorded with a scanner to provide real-time data and automated reports on volumes, berms and, for the Whitby project, slopes.

The laser scanner was configured to measure an important section of the cliff face at 60-minute intervals each day, with each scan sampling the cliff face at a resolution of 10 cm, generating more than two million points. With such vast quantities of data to process, the device was paired with automated analytical software that streams live information direct to the analysis team in Durham.



Areas being monitored

Screen shot of data showing coastal change

By monitoring small changes over time, geologists can alert engineers to remedial work that needs to be done to prevent a catastrophe. According to Dr Nick Rosser, from the university's Department of Geography, SITEMONITOR LIVE enables them to measure small-scale movements and rockfalls with such high resolution and frequency that, "up until now would not have been possible".

Using a bathymetric system, further environmental data was also captured to attempt a better understanding of the impact of higher sea levels and turbulent weather on coastal erosion. Until recently, research had relied on anecdotal evidence, suggesting a simple cause-and-effect between waves and erosion. Fresh data from this site indicates that erosion happens over a longer period of time than once thought and is often attributable to a range of factors, including freezing and thawing, temperature changes and friction from rising and falling tides.

Moisture in rocks, caused by water leaking from beneath, is one of the most common signs of unstable land, so laser scans show whether there has been an increase in this over time. Data from weather sensors is also used to show a link between rainfall and water in the rock face.

Each of the surveying methods is valuable in its own right, though they work best when combined. While terrestrial scanning generates high-resolution data, able to detect minute change, airborne surveys are lower resolution, but cover a much wider area in less time and can show long-term trends.

The Whitby project has become one of the world's most pioneering coastal erosion programs, largely thanks to the depth and scope of the datasets. As work continues at the site, new techniques and methodologies are being developed—including algorithms to mine further information from time-series 3D scan data to show where land has become unstable.

Until this project got underway, the SITEMONITOR system had been used mainly in mining, but other industries are starting to see the benefits. By closely monitoring previously hard-to-reach areas in real-time, site managers are able to detect even small changes with greater speed and accuracy than before and, crucially, take appropriate action.

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

Graham, *continued from page 48*

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	-2	-2	-2	0	0
0	0	-2	16	-2	0	0
0	0	-2	-2	-2	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

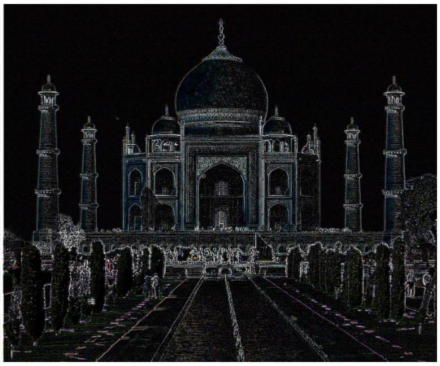


Figure 2: Edge Enhancement

individual preprocessed pixels ("flattening") into a conventional artificial neural network. The combined process is termed a Convolutional Neural Network (CNN) even though the preprocessing steps are performed using conventional image processing algorithms. Note that we can actually increase the data size (and usually do) by using not one convolutional filter but a large set that do different things such as "enhance left to right diagonals", "enhance right to left diagonals", etc. This large collection of enhanced images is then reduced in the pooling step. This provides a very rich set of distinct features to feed into the conventional ANN.

When processing multispectral imagery, we can use cross channel information in the preprocessing steps (e.g. mix the red and blue channels). When processing LIDAR data, we simply treat the third dimension (e.g. height) as another channel.

The use of CNNs in LIDAR data processing is really in its infancy. We are seeing some prototype applications coming to market but the mainstream use of CNNs in production and analytic processing is still a bit in the future. While CNNs show great promise, they do have some drawbacks. They obviously require tremendous compute resources. This is being addressed by cloud services such as Microsoft Azure and Amazon Web Services who offer ANN engines (such as MXNET) "out-of-the-box." One current handicap to CNN is the lack of robust training data. Unlike predictive algorithms, a neural network must be fed examples of what it is to detect. If we want to train a CNN to extract buildings, we must have a set of multiple copies of every building we want detected! Over time it is likely that a set of public domain training sets (similar to the idea of MNIST) will become available. This will dramatically accelerate the adoption of useful CNNs for LIDAR processing.

In spite of the drawbacks of CNNs, they show great promise toward solving certain types of recognition problems. Chances are, if you work in LIDAR data from the production or analytic side, a CNN is in your future.

Lewis Graham is the President and CTO of GeoCue Corporation. GeoCue is North America's largest supplier of LIDAR production and workflow tools and consulting services for airborne and mobile laser scanning.

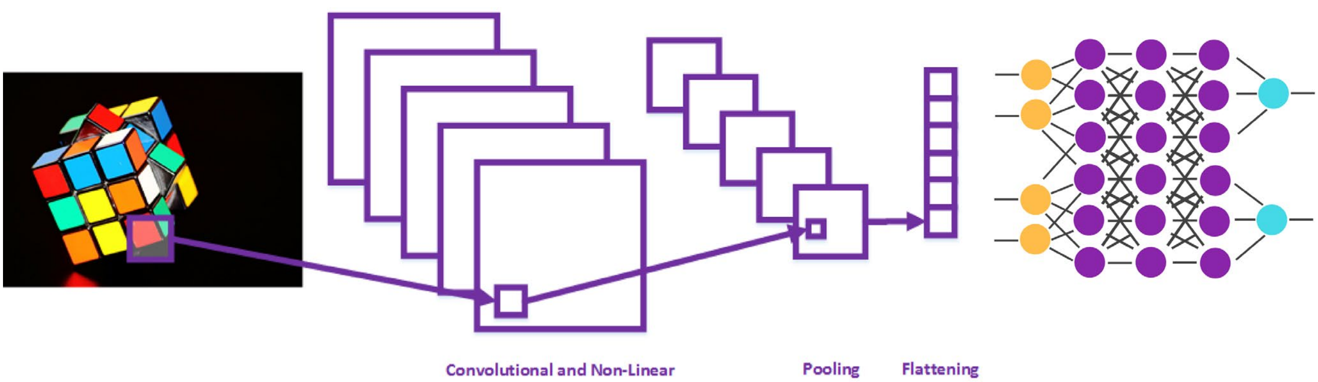


Figure 3: The complete Convolutional Neural Network (CNN)

Convoluted Thinking

This month I was going to discuss how to fly and process LIDAR data for 27 cents per km^2 but Allen (Cheves, the publisher) reminded me that I owe him part 2 of the neural networks discussion. Oh well, must save that processing secret for another time!

Last month I provided a review of the rebirth of the artificial neural network (ANN) as one of the more popular approaches to solving computational problems. In fact, it has become so ubiquitous that off-the-shelf libraries exist, allowing you to quickly roll your own ANN analytic system. Their primary use has been in systems where the problem is classification (dividing things into categories) and the problem space is *fuzzy* with a lot of training data available. One of the outstanding successes of ANN has been in natural language processing (think Siri, Google, Alexa and so forth).

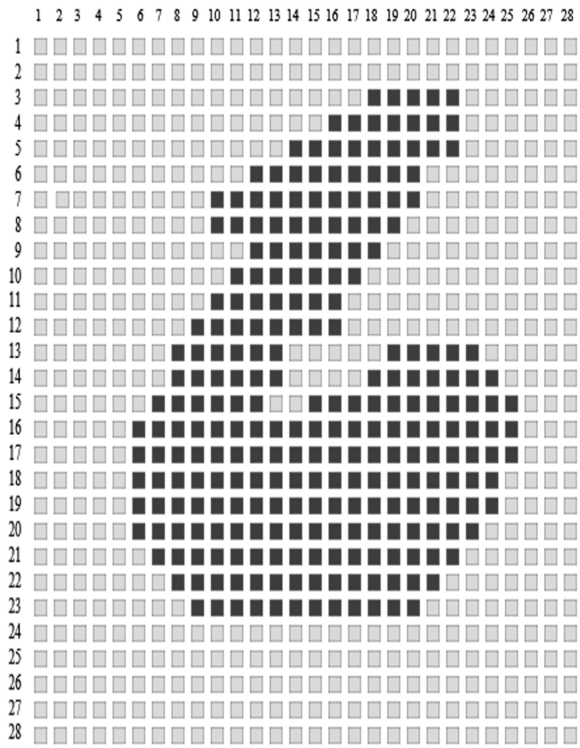


Figure 1: An image of a digit from MNIST

Of course, our interest is in applying this technology to LIDAR and image processing problems. If you followed part one of this article, you noticed that a bare bones ANN requires an input per pixel. In LIDAR processing, this would be an input per point. Even the little digit recognition problem that I referenced at the end of the article, with its 28 x 28 input images comprising the MNIST data set (see an example digit in **Figure 1**), requires a whopping 784 input neurons (one per input pixel). This approach will not scale to a real-world LIDAR/image data set.

A critical fact with imagery, LIDAR and other select data types such as speech is they have spatial or temporal *coherence*. This means that the closer two points are to one another in space or time, the more likely they are to be related to the same feature. Conversely, the further apart, the less likely. This is very easy to visualize in imagery/LIDAR. If we view, top-down, an image of a rectangular building roof that is 10 m x 20 m in world coordinates, then two pixels more than 22.4 m (the length of the diagonal) apart cannot both be part of the same building roof. We can take advantage of this localization by preprocessing the imagery into blocks. Since, at the end of the day, we are interested in extracting features from the data, we may as well process the data into blocks with enhanced feature primitives (such as edges). The time-tested way to do this is by running *filters* over the image in an operation called *convolution*. An example of an edge enhancing filter is shown in **Figure 2**. If we then subsample these feature blocks (in neural network jargon, this is termed "pooling") we can reduce the input data size to something more amenable to neural network input.

A block diagram of this series of processing steps is shown in **Figure 3**. The general flow is to enhance features using various convolution filters into groups of enhance images, subsample these into blocks ("pooling") and then feed these

continued on page 47

This point cloud was generated using the Pixels-To-Points™ tool and 192 overlapping drone-collected images.
Create a high density point cloud from UAV-collected images
GlobalMapper
LiDAR Module
NOW WITH PIXELS-TO-POINTS™
Download a FREE trial today!
Blue Marble GEOGRAPHICS
Mind the gap between world and map
globalmapper.com/download

Imagine endless solutions for your endless applications.

MR-2 Receiver

B125 Receiver Board

SRG-1 Integrated Receiver

Precision Navigation, Guidance, Automation and Asset Management. We offer a wide selection of OEM solutions that meet even the most unique market demand. From components to receivers, antennas and beyond, our innovative positioning technology can be integrated into your branded products easily and seamlessly.

topconpositioning.com/OEM

TOPCON