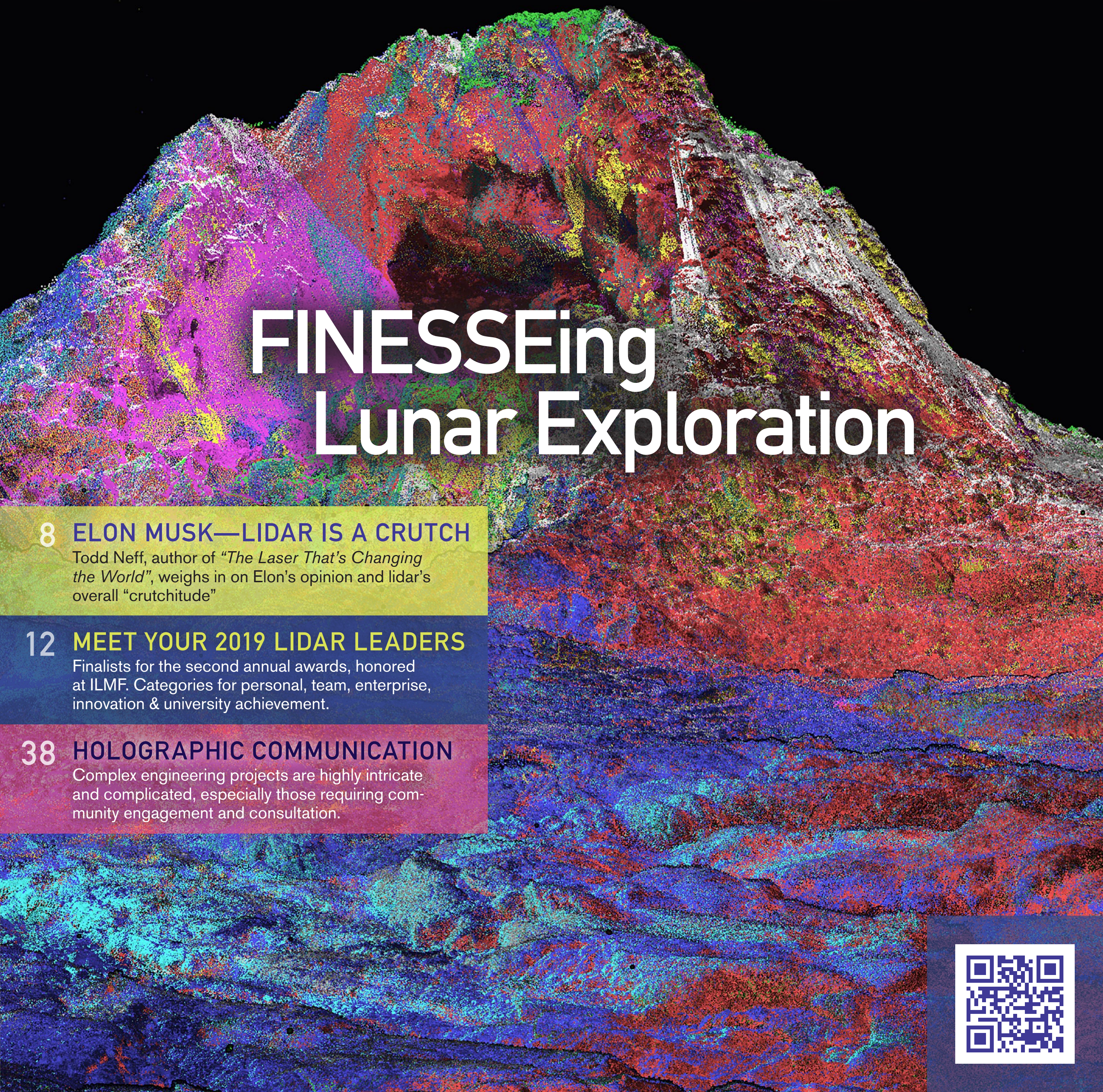
VOLUME 9 ISSUE 1

LIDAR MAGAZINE

JAN/FEB 2019



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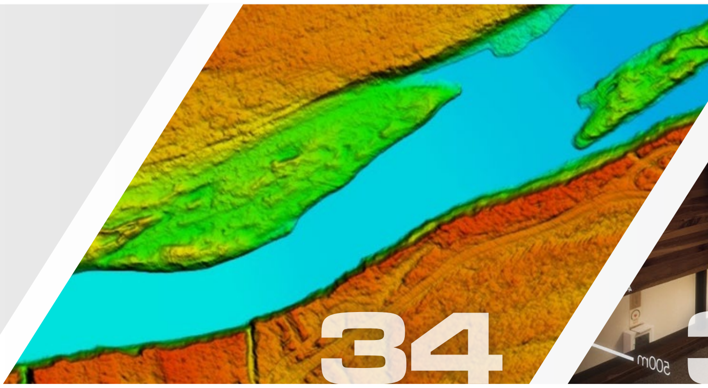

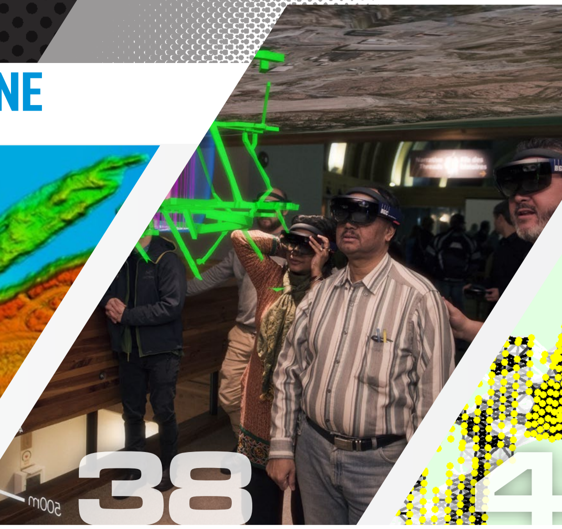

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LIDAR To Go!

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◀ ON THE COVER

Scan of an isolated "spatter cone" found within Craters of the Moon National Monument, a region of the Snake River Plain in southern Idaho. These mini-volcanoes rise as much as 20 m (65 ft) or more above the expansive lava flows within the park. Point cloud captured by the Akhka R3 KLS backpack mobile lidar system, color coded by each minute of data collection.

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**

New Year's Day is every man's birthday

Charles Lamb was a favorite in my high-school English literature, so let's enjoy his pithiness as we set out on 2019. Lidar is advancing—at the speed of light, I suppose—and we're all on board. We've made some significant changes to the magazine, aimed at providing an even more effective forum for authors and advertisers. We will publish six issues per annum, with a rigorous schedule, plus two special issues in 2019, on topical themes reflecting current directions in the industry: one on sensor integration trends and the other, aerial imaging trends. We've published the schedule, plus guidelines for prospective authors, at lidarmag.com/submissions, so please keep the articles flowing. If the stream proves to be in spate, we can publish digital-only as well.

We are about to celebrate the accomplishments of leaders in our field at the Lidar Leader Awards, a joint initiative of Diversified Communications and *LIDAR Magazine*. These will be presented in plenary session at the International LiDAR Mapping Forum during Geo Week in Denver at the end of January 2019. There are five categories, the first three the same as in 2018: Outstanding Personal Achievement in Lidar; Outstanding Team Achievement in Lidar (2-99 members); and Outstanding Enterprise Achievement in Lidar (groups of 100+). Outstanding Innovation in Lidar is a new category, to honor recent arrivals that appear to be ground-breaking but are not yet established. Eligible innovations can qualify from a company or an individual and can be technology, a product, or a business model in the realm of geospatial technologies, which must be on the market for less than one year, or not yet on the market but demonstrably operational. Also new is Outstanding University Achievement in Lidar, to recognize universities and their researchers. It is open to all universities, students and teams within the university, who must demonstrate an exceptional achievement within the realm of lidar technology and present it, in no more than five minutes, during a University Lightning Round on 28 January 2019, in front of a panel of experts and conference attendees. Presentations will be evaluated on: most commercially feasible; most innovative use of lidar; and "people's choice".

A large number of deserving candidates were nominated and the adjudication process was no less demanding than last year. Once again, the runners up will be announced from the podium, to be honored by the audience, then the winners will be invited to the dais to receive their awards. The successful nominations this year, given here in alphabetical order, embody a galaxy of lidar talent:

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SPATIAL MEDIA

USIBD U.S. Institute of BUILDING DOCUMENTATION

- Outstanding Personal Achievement in Lidar: Karl Heidemann, physical scientist, USGS (retired); Karen Schuckman, assistant teaching professor, Department of Geography, Pennsylvania State University
- Outstanding Team Achievement in Lidar: Global Mapper Team at Blue Marble Geographics; JALBTCX Team; Jie Shan, professor, Purdue University and Charles Toth, research professor, The Ohio State University (for their book, *Topographic Laser Ranging and Scanning*, of which the second edition appeared last year)
- Outstanding Enterprise Achievement in Lidar: Geoscience Australia (for ELVIS Elevation Infrastructure); NASA ICESat-2 Mission—NASA Goddard Space Flight Center; Woolpert
- Outstanding Innovation in Lidar: AEye (for its AE110 Artificial Perception System); ASTRALiTE (for its bathymetric lidar system for UAVs); Velodyne LiDAR (for its VLS-128)
- Outstanding University Achievement in Lidar: candidates will be chosen at the University Lightning Round on 28 January 2019.

We will know the winners soon—mark Tuesday 29 January 2019 in your calendar—and we will give them the opportunity to write short articles for the magazine, so you will know more about what they have done. Thank you for making such superb nominations.

The appearance of Shan and Toth above underlines the importance of authoritative books to our community. In this issue, David Maune provides information on an important new publication—the third edition of *Digital Elevation Model Technologies and Applications: The DEM Users Manual*[1]. Secondly, we review an account of lidar's technology, history, applications and people, aimed at a broad market[2]. This popular volume contrasts with, yet complements Atlanta-based early adopter/researcher Adam Patrick Spring's magisterial history of terrestrial laser scanning, which is coming out in two parts in *PE&RS* in the first half of 2019. Part one deals with the origins of laser scanning in space and defense applications, whereas part two examines how applied solutions/technologies transitioned into industry. Both articles have been written and refined over more than ten years.

To enliven my editorials, I have been drawing to your attention, in a whimsical way, gems I have unearthed while scanning my archive, or plowing through issues of *The Economist*. Indeed, as I glance at pages torn from older issues of the newspaper of the dismal science, I am pleased that topics its journalists found interesting also matter in our world, for example the use of UAVs to carry medicines and blood samples (rather than pizza)[3], the addition of solar panels to UAV airframes to extend endurance, or lidar discoveries at Preah Khan of Kompong Svay. An interesting piece late last year[4] featured Gipsformel, the plaster-cast manufactory of Berlin State Museums. Their products enable irreplaceable 3D works of art, such as friezes and statues, to be reproduced. The art world increasingly frowns, however, on taking molds directly from originals; the solution, of course, is laser scanning.

Another piece[5] reminds me of my surveying lectures in the Fall of 1971, covering standards of length. On 16 November 2018, the Member States of the International Bureau of Weights and Measures (BIPM) voted to revise the Système international d'unités (SI, or the metric system), changing the world's definition of four of its base units. All SI units will now be defined in terms of constants that describe the natural world. This will ensure the future stability of SI and facilitate the use of new technologies, including quantum technologies, to implement the definitions. The kilogram, ampere, kelvin and mole are redefined in terms of constants; the new definitions, which come into force on 20 May 2019, are based on fixed numerical values of the Planck constant, the elementary charge, the Boltzmann constant, and the Avogadro constant, respectively. This is a dramatic advance, yet the US is one of a handful of countries, such as Liberia and Myanmar, that have not adopted SI. So UAV lidar folk can continue to claim two inches from 100 meters, 5 centimeters from 300 feet, or, perhaps, both of the above. Should we sink a pint to that?

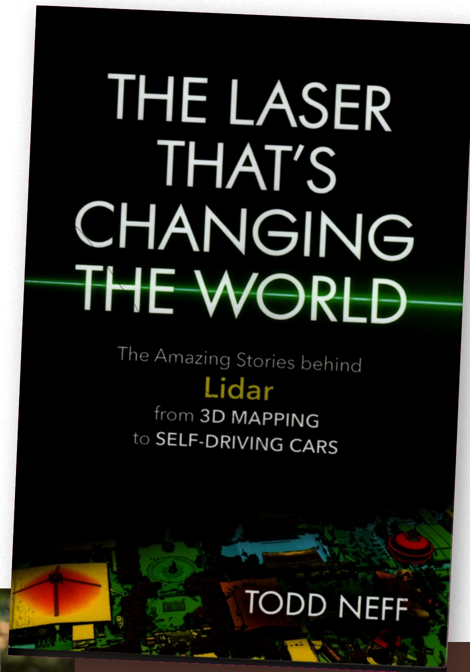
A. Stewart Walker // Managing Editor

1 Maune, D. and A. Nayegandhi (eds.), 2018. *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 3rd edition, ASPRS, Bethesda, MD, 652 pp.
2 Neff, T., 2018. *The Laser That's Changing the World: The Amazing Stories behind Lidar from 3D Mapping to Self-Driving Cars,* Prometheus Books, Amherst, New York, 314 pp.
3 Anon, 2018a. Pies in the sky: drone deliveries take off, *The Economist*, 429(9115): 74-75, 27 October.
4 Anon, 2018b. True copies: artistic reproduction, *The Economist*, 429(9122): 81, 15 December.
5 Anon, 2018c. Weighty matters: metric units, *The Economist*, 429(9118): 78-79, 17 November.

BY STEWART**WALKER**

The Laser That's Changing the World

The Amazing Stories behind Lidar from 3D Mapping to Self-Driving Cars



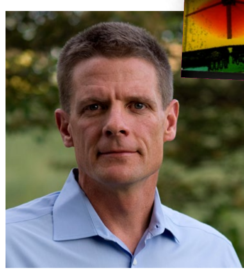
BY TODD NEFF

- Prometheus Books, Amherst, New York, 2018.
- 228 x 154 mm, 314 pp
- 24 black and white illustrations, numerous notes and references, index.
- Paperback, ISBN 978-1-63388-466-3, $19.00.
- Also e-book, ISBN 978-1-63388-467-0, $11.99.

Unlike most books reviewed in these pages, *The Laser That's Changing the World: The Amazing Stories behind Lidar from 3D Mapping to Self-Driving Cars* is not an academic tome but a popular work, aimed at the mass market. Todd Neff is an award-winning science, environment and healthcare journalist, who decided that lidar people, technologies and applications are sufficiently interesting and significant to bring them to the attention of readers worldwide.

My heart pounded at the title of the first chapter, "Hutchie", the nickname of the traditional institution of education I attended for middle and high school in Scotland. No, of course not, it's about Edward Hutcheson Synge, an Irishman who figured strongly in the early days of lasers. Yet I was not entirely disappointed at the lack of links to Scotland: I learned that Allan Carswell's mother hailed from the Isle of Lewis, a dreich, windswept, evocative island off Scotland's west coast. It was one of those pleasing coincidences that when I read the section on Optech's early days, my bedtime reading was *The Black House*, the second volume of Peter May's Lewis trilogy.

The 17 short chapters encompass remarkable breadth. There is so much to celebrate about lidar—scientific and engineering breakthroughs on the one hand and valuable improvements to the quality of life of our planet's inhabitants on the other. There are chapters on the early history, then the book follows a structure where a development used for a particular application is described and its advances and adoption traced, often ending with a segue into the next chapter. Neff frequently refers back to earlier developments that provided foundations or components for the one being discussed, an approach that deepens the appeal of the book. He's not afraid to draw in complementary technologies, such as radar, sonar or GPS, where appropriate. Readers will vary in their preferences, but your reviewer found the material on space, archaeology and autonomous vehicles to be engaging; the narrative surrounding the various DARPA challenges is riveting. One of the prevailing themes is the remarkable abilities of the inventors and developers who made the big advances. Neff's tributes, moreover, frequently stress these pioneers' acumen in actually making things—cutting metal, joining wires and pipes, buying


Author Todd Neff

components and so on—while fully exploiting their brilliance in physics, engineering or other specialisms.

The book's scope reminds those of us from the geospatial world that we have no monopoly on the use of lidar. Surveying and mapping, massively important as they are, benefit from lidar's precise positioning, while diverse applications, such as detection of gas leaks, use other features of the technology. It's strange to open a popular book and feel like a spectator watching the very events described unfold. The book opens at the 2017 ILMF conference and chapter 12 visits the 2018 event. The front cover graphic is from Harris. There are numerous mentions of people we know, mostly encomia upon lidar's movers and shakers, but some rather less reverent—the urbane Alistair Jenkins may or may not quibble at being described as a "guy with a high-end British accent" (page 113)! Neff does well to see so much, talk to so many experts, then distill what he has learned into succinct, captivating accounts.

Prometheus Books has produced this volume well. There are hardly any typos or obvious errors, though "Victoryville" ought probably to be "Victorville" (page 202). There are 38 pages of notes, in the style of a professional history or biography, authenticating statements in the book by referring to the author's communications with people, providing references, or giving further information. These provide readers with a starting point to research lidar in more detail, especially the historical aspects. The 40-page index is helpful, for example to return to a development that the author cites in the context of something newer.

> "The lidar community ought to read this, as should general readers excited by modern technologies and the benefits they bring to society."

Some readers of *LIDAR Magazine* may quibble at Neff's colloquial style and, indeed, a few words may cause difficulties for those whose variant of the English language is not the US one (we are hit by "grokking" as early as page 7, for example, and "not too shabby" on page 49; "hired" is apparently more intransitive than transitive). Others may tire of his repetitive descriptions of the innovators—the stars with whom the book is studded—"Fred was born in x, got his PhD from y, joined z in 19xx, was wearing khakis and polo shirt when I met him, brewed tasty coffee and is a great guy" is not everyone's ideal introduction, yet something along these lines is required to give the technologies a human slant while not compromising the book's breathtaking pace. Experts may take issue with some of the historical or technical details—the link between forest measurement and Hugershoff, for example, may be worth another look.

Despite those dangers, *The Laser That's Changing the World: The Amazing Stories behind Lidar from 3D Mapping to Self-Driving Cars* is a considerable achievement. Neff has made his short history of lidar into a compelling narrative and has brought the technology we cherish to life through straightforward explanations of principles and a pleasing focus on the characters whose achievements have justified the phrase, "We are standing on the shoulders of giants". The blurb on the back cover includes endorsements from renowned lidar luminaries, so the book's success is rightly off to a fast start. The lidar community ought to read this, as should general readers excited by modern technologies and the benefits they bring to society. Historians of lidar will find the book invaluable. Your reviewer will use it to brief himself before interviewing a company to prepare an article. Reasonably priced and requiring only a couple of evenings to read, this book should deservedly succeed. The one-page conclusion at the end of the final chapter promises more applications of lidar in the future, developed by new generations of brilliant, creative people. Let us hope that Neff keeps us informed of these with a second edition in a few years.

Stewart Walker, Managing Editor, *LIDAR Magazine*.

BY TODD NEFF

Elon Musk is Right: Lidar is a Crutch

Elon Musk has been right about a lot of things. That the web would enable new forms of payment (PayPal). That the rocket-launch industry was ripe for disruption (SpaceX). That the combination of falling hardware prices and innovative financing could open up many more roofs to solar energy (SolarCity). That there was a market for electric cars (Tesla). Heck, he may even be right that electric skates hurtling through tunnels can slice the Gordian knot of metropolitan traffic jams (The Boring Company).

Musk was also right when he called lidar a "crutch" when it came to self-driving cars. Where he's not right, though, is that the technology's crutchitude is somehow a reason not to employ lidar—which uses lasers to scan the world around them, identify objects and characterize surroundings to centimeter accuracy—as a fundamental sensor on self-driving cars. Musk and almost everyone else in the business recognize self-driving cars and trucks as the future of automotive transportation. Every major automaker, not to mention the likes of Apple, Uber, and Google spinoff Waymo, has an autonomous vehicle program going. Billions of dollars a year are pouring into dozens of efforts involving thousands of wickedly smart people around the world.

These systems build on decades of work in academia and corporate research labs. The biggest challenge with vehicle autonomy has been, and remains, developing computer brains capable of handling whatever side streets, dirt roads, parking lots, six-lane highways, roundabouts, construction zones, railroad crossings, and so on throw at them (Amish buggies, kids leaping out from between cars in pursuit of bouncing balls, snowstorms on country roads, idiots darting across four lanes to exit ramps, school-bus drop-offs…). The second-biggest hurdle—and one inextricably enmeshed with the computer-brain challenge—has been to make sure the computer brains are acting on accurate representations of the world they're attempting to navigate.

That's where sensors come in. Cameras can tell a red light from a green one, see the difference between a UPS truck and an ambulance, and capture the dancing lights of a police car parked on the shoulder. Radar bounces microwaves off objects near and far, day and night. Lidar does that, too, but using light with wavelengths thousands of times shorter than those of microwaves. Shorter wavelengths mean sharper resolution. So where radar can tell you something's there, lidar can tell you if a surprise moving across the road is a trash bag caught in the wind or a boy on a Big Wheel.

In daylight, cameras can do that, too, but not so much in the dark, which is why the autonomous vehicle development world has by and large settled on sensor fusion, which involves a combination of lidar, radar and cameras. The strengths of one sensor compensate for the weaknesses of others. Make no mistake, however: of these increasingly fused sensors, lidar has been the most vital in moving self-driving transportation forward. Consider the difference between the first DARPA Grand Challenge in 2004, in which there were no finishers despite a relatively straightforward desert course, and the 2007 DARPA Urban Challenge, which featured the first commercial Velodyne lidars. The majority of the 11 finalists finished a far more difficult and chaotic course. The computers had become faster and the software, better, certainly, yet the new lidar was decisive.

"…the autonomous vehicle development world has by and large settled on sensor fusion, which involves a combination of lidar, radar and cameras. Make no mistake, however: of these increasingly fused sensors, lidar has been the most vital in moving self-driving transportation forward."

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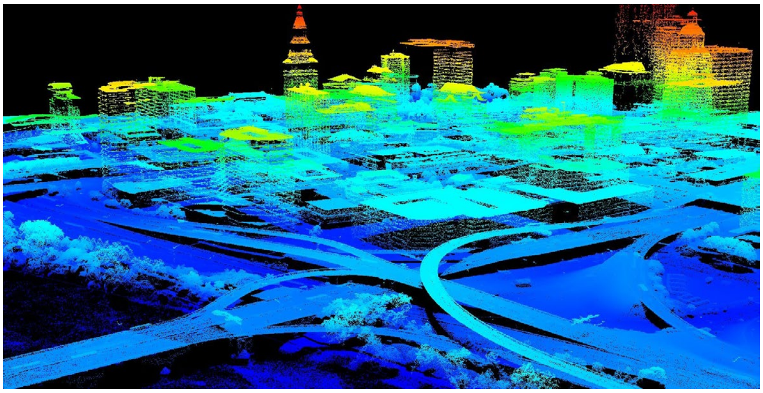


ASPRS Honoring Dr. Qassim Abdullah with Lifetime Achievement Award

Dr. Qassim Abdullah, Ph.D., CP, PLS, has been selected to receive the American Society for Photogrammetry and Remote Sensing (ASPRS) Lifetime Achievement Award. The distinction, formerly known as the Honorary Member Award, is the highest honor the society bestows on any individual. It recognizes Abdullah's distinguished service to ASPRS and in advancing the science and uses of remote sensing, photogrammetry and related disciplines.

Abdullah, chief scientist and senior associate at Woolpert, started his career as a civil engineer but was quickly drawn to surveying and photogrammetry, in which he earned his master's and doctoral degrees. He said there has never been a dull moment in his 40-year career, thanks to ever-evolving geospatial sensor technologies.

Dr. Qassim Abdullah (right) visited the Grand Canyon recently with his younger son, Omar. Abdullah has been married for 40 years and has three children and four grandchildren.

"Although I have participated in the development and introduction of many powerful geospatial tools (the digital camera, airborne GPS, inertial measurement unit, etc.), lidar has been the technology that continues to fascinate me the most," Abdullah

When not discussing lidar and other geospatial topics, Dr. Qassim Abdullah enjoys running and competing in 50K and marathon races. He regularly runs about 25 miles a week. "Besides the health benefits, running helped me meeting new friends and taught me a great deal of patience, when you run 30 miles at a time and your body begs you to wrap it up, running teaches you to take it one mile at a time and that mile 26 will never come before finishing mile 25, it is a virtue of discipline and patience," he said.

said. "In the mid-1990s, I was one of the few lucky individuals who had the opportunity to participate in the development of the first high-altitude lidar systems, which evolved to the ALS lidar system of today. Such a role gave me a better understanding and therefore appreciation of this technology. Lidar may sound like a simple physics, but in reality it is mind-boggling technology."

Abdullah was the creator and principal author of the new ASPRS Positional Accuracy Standards for Digital Geospatial Data Standards, which is focused on lidar data and digital imagery. He has been involved in the introduction of the new generation of lidar, most recently evaluating Geiger mode and single photon lidar in his role as a consultant for the U.S. Geological Survey (USGS). Through his data analysis, technologies evaluation and publications, Abdullah provides guidelines, conclusions and recommendations on the usefulness of the data from the new sensors for topographic mapping. He also is a member of Unmanned Aircraft Systems Standardization Collaborative, developing standards to facilitate the safe integration of drones into the U.S. National Airspace System.

Abdullah said helping author mapping standards and publishing his monthly "Mapping Matters" column in the PE&RS Journal have been "a few of the coolest things" he's done in his career, while he said teaching graduate courses and workshops on geospatial subjects also has been immensely rewarding.

In addition to teaching classes at Penn State University and the University of Maryland, Dr. Qassim Abdullah conducts countless conference presentations each year. Here he is presenting at the 2018 Alaska Surveying and Mapping Conference.

"Writing and teaching makes me evaluate the industry from a layman's perspective, and pushes me to read, investigate, test and develop the right answers and the needed applications," Abdullah said. He added that his advice to those starting out in the geospatial field is to dedicate their careers to a topic they are most passionate about, that they can pursue with integrity, curiosity and hard work. "Passion drives you to persevere, curiosity pushes you to create and hard work gives you the time you need outside your daily routine. Like me, I tell them, they will find themselves working, reading or analyzing issues during holidays and weekends, while others are enjoying their favorite sports on television."

That passion continues to carry Abdullah forward. Looking ahead to the future of geospatial technologies, he predicts a laser-based camera system that will be a lidar and multispectral camera at the same time.

"It will be a 3D imaging system that you can fly in the middle of the night," he said. "But I don't want to reveal too much about that now, as I am planning to publish an article soon on the blueprint of the design."

Abdullah also just published a blog on geospatial trends for 2019, with topics that include big data, real-time GIS, robotics platforms, miniaturized sensors, cloud computing, marrying BIM to GIS, smart cities, mapping-as-a-service, and more. That was posted on woolpert.com in mid-January.

Abdullah said he is grateful to the industry in general and to ASPRS specifically for this most recent recognition.

"I am surrounded by this community of intelligent and creative friends and colleagues, who provide me with an invaluable technical and dynamic environment," Abdullah said. "I am honored to be a part of this vital, thriving industry."

The ASPRS Lifetime Achievement Award will be presented to Abdullah on Tuesday, Jan. 29, during the ASPRS Annual Conference and International Lidar Mapping Forum in Denver.

LIDAR LEADERS

LIDAR LEADER AWARDS

BROUGHT TO YOU BY

ILMF & LIDAR MAGAZINE

For the second year in a row, we've opted to celebrate the accomplishments of leaders in our field at the Lidar Leader Awards, a joint initiative of LIDAR Magazine and the organizers of the International LiDAR Mapping Forum (ILMF). Over the pages that follow, we've highlighted some of the finalists from each award category. As you'll find, the nominations embody a galaxy of lidar talent. All winners will be provided the opportunity to highlight their perspectives in an upcoming edition of the magazine.

Five categories were offered this year:

Outstanding Personal Achievement in Lidar

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

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

Outstanding Innovation in Lidar *(New for 2019)*
This category was created to honor recent projects or products that appear to be ground-breaking.

Outstanding University Achievement in Lidar *(New for 2019)*
This category is open to all universities, students and teams within the university, who must demonstrate an exceptional achievement within the realm of lidar technology.

Editor's note: The text that follows has been excerpted from original nominations and in no way defines the views or opinions of the award committee, the organizers of ILMF or LIDAR Magazine. Some text has been edited for clarity and length.

Outstanding Personal Achievement

PERSONAL FINALIST Karen Schuckman, Assistant Teaching Professor, Department of Geography, Penn State

For the past two decades, Karen Schuckman has made numerous noteworthy contributions and has sustained forward-thinking leadership in advancing the mainstreaming of lidar technologies in the geospatial/ mapping community. Her activities range from leading the lidar data acquisition team in the first statewide lidar mapping program in North Carolina, to initiating formation of the lidar Division within ASPRS, coordinating early standards development efforts, and now teaching aspiring and mid-career professionals for Penn State's Online Geospatial Education Programs. Karen has undertaken several leadership roles, such as the North Carolina FEMA floodplain mapping, where she was the principal project manager for the EarthData team, including a team of developers working with survey and engineering partners. Their work became the model that stimulated development of standards, development of commercial software, and led to broad acceptance of lidar as a mainstream mapping tool. Karen has been an active participant in ILMF since its inception provided essential leadership to bring together key manufacturers, government experts and policymakers, and early users. Her efforts supported the growth of ILMF as a respected gathering of private practitioners and government agencies, paving the way for transferring the emerging lidar technology into operational practice.

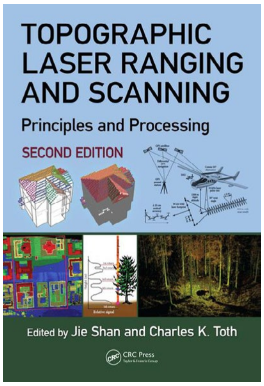
Karen transitioned her energies to teaching when she joined the Department of Geography faculty at Penn State in 2007. At that time, the Online Geospatial Education Program focused on GIS and lacked content in the areas of photogrammetry and remote sensing. Over the 12 years she has been at Penn State, Karen has personally taught over 1,000 students and has spearheaded the evolution of the program to include a Graduate Certificate in Remote Sensing and Earth Observation launched in 2017.

PERSONAL FINALIST Karl Heidemann, Physical Scientist, USGS (Retired)

Hans (Karl) Heidemann led the development of lidar standards and specifications within USGS and served as their representative on various inter-agency and national and international lidar commissions. He provided technical expertise on lidar contracting and quality assurance for the National Geospatial Program (NGP) and the 3D Elevation Program (3DEP). He authored the USGS Lidar Base Specifications (LBS) published in 2012 and revised in 2014 and 2018. This seminal document provided the first lidar guidance centered on the primacy of the point cloud as source data, opening the way for consistent use of lidar data for diverse applications and establishing data handling practices that substantially improve capacity for cross-collection, multi-vendor, multi-instrument data analysis. Beyond its use for the NGP and 3DEP, the LBS has become the base of countless lidar collection contracts nationally and internationally. The release of the LBS v1.3 was Karl's last official act prior to his retirement from USGS in 2018. Joining the USGS at the EROS Center in 2008, Mr. Heidemann revamped lidar data ingest and distribution for the Center for Lidar Information Coordination and Knowledge (CLICK) portal and supported numerous collection and scientific efforts including a national collection for El Salvador. He played a leading role in the integration of lidar derived data into the National Elevation Dataset (NED) and developed the standards for the now ubiquitous process of hydro-flattening topographic DEMs for the 3DEP. He has been a leading advocate of a USGS migration from traditional quad-based tiling to a CONUS-based Cartesian system more suitable for seamless lidar data management. In 2014, Mr. Heidemann was a co-author of the ASPRS Positional Accuracy Standards for Digital Geospatial Data and established the ASPRS standard for the number of lidar QA/QC checkpoints in vegetated and non-vegetated terrain. He is a long-standing and active member of ASPRS, currently serving as the Chair of the Lidar Certification Review Committee. In private industry, he developed lidar data calibration, automated classifications, surface generation, and data management procedures widely used today, and he has conducted workshops and classes in lidar for both the public and private sectors.

LIDAR LEADERS

Outstanding Team Achievement



TEAM FINALIST Topographic Laser Ranging and Scanning Team—Drs. Jie Shan & Charles Toth

The publication “Topographic Laser Ranging and Scanning” is a seminal reference book for anyone seriously involved in the lidar industry. There are few comprehensive reference books on this subject, and none that compares in overall content and technical depth. This book by Shan and Toth is now in 2nd edition. It represents a culmination of decades of experience in lidar and mapping for these two prominent individuals.

Topographic Laser Ranging and Scanning”, 2nd Edition

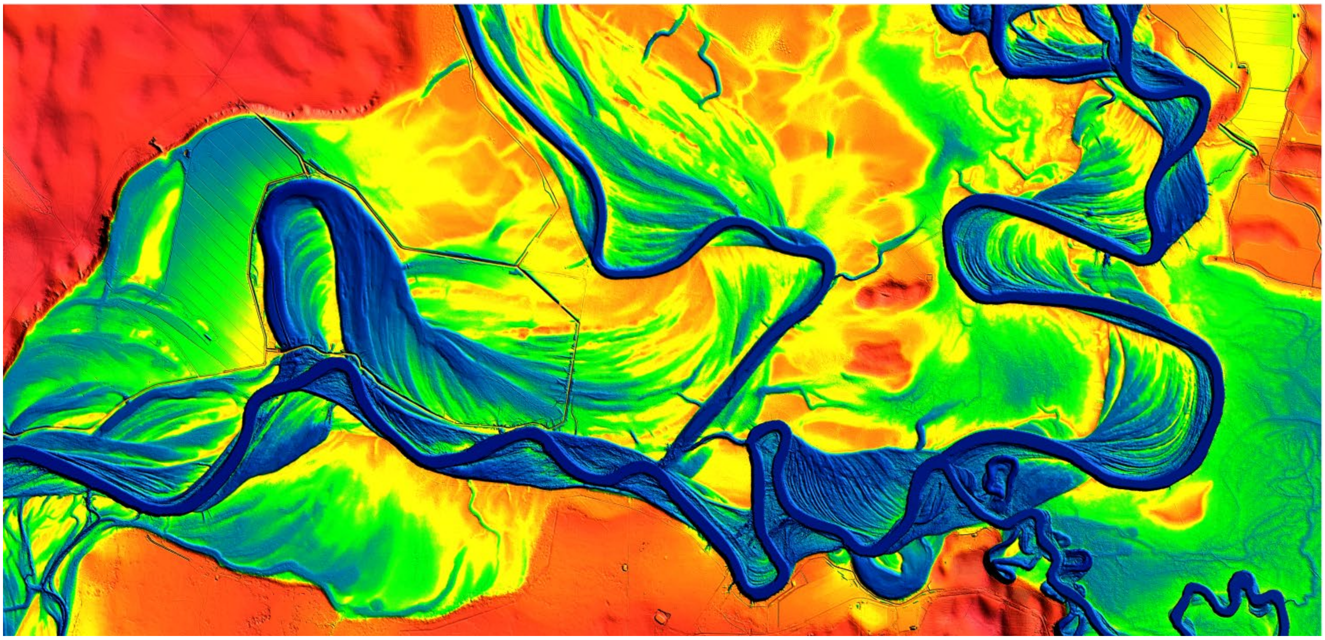
TEAM FINALIST Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) Team

The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) team leads operations, research and development of airborne lidar bathymetry and complementary technologies for the U.S. government. Formed in 1998, JALBTCX supports the National Coastal Mapping Program (NCMP) requirements of the U.S. Army Corps of Engineers (USACE), and the Airborne Coastal Survey mapping requirements for the Naval Oceanographic Office. The NCMP's high-resolution elevation and imagery data is collected along U.S. shorelines on a recurring basis.

JALBTCX Director Jennifer Wozencraft, a research physical scientist in the USACE Engineer Research and Development Center's Coastal and Hydraulics Laboratory, heads a team of engineers, scientists, hydrographers and technicians, including Lauren Dunkin, Joseph Harwood, Nicholas Johnson, Chris Macon, Molly Reif and Charlene Sylvester. This team led the development of the Coastal Zone Mapping and Imaging Lidar (CZMIL), which acquires airborne bathymetric and topographic lidar and digital and hyperspectral imagery in a single airborne platform. The JALBTCX team has acquired airborne lidar bathymetry multiple times along the conterminous United States coastline (including the Great Lakes) as well as in Alaska, Hawaii and the U.S. territories. Additionally, the team acquired emergency response data following natural disasters such as Katrina, Sandy, Matthew, Irma, Maria and Florence. The data is used to analyze beach and dune response to storms, assess shoreline changes and support coastal resiliency.

Publicly available through the National Oceanic and Atmospheric Administration's Digital Coast Partnership, the data also can be used for engineering purposes.

By supporting research and development and leveraging work with private industry, the government and academia, the JALBTCX team continues to advance airborne lidar bathymetry, coastal mapping, charting technology and data applications to the benefit of all involved.



A section of the Murray River as featured in ELVIS.
Geoscience Australia

Outstanding Enterprise Achievement

ENTERPRISE FINALIST Geoscience Australia—ELVIS Elevation Infrastructure

Geoscience Australia has developed an online shared infrastructure called ELVIS elevation (Elevation.FSDF.org.au) to access and discover lidar and DEM datasets across Australia. A national collaboration between Geoscience Australia, NSW Government Spatial Services, Tasmanian Government Department of Primary Industries, Water and Environment, Queensland Government Department of Natural Resources, Mines and Energy and ACT Government enables users to easily discover and freely access Australia's highly valuable, open lidar and DEM data from various sources in one location. ELVIS enables open data holdings to be uploaded and managed in a federated infrastructure by each state and territory government custodian of these elevation products. Through this highly successful collaboration, the volume of elevation data available through ELVIS has risen significantly since late 2016 from 3TB to 400TB today. The key to achieving this growth has been in GA's extensive engagement with government jurisdictions around the country and illustration of the mutual benefits of a collaborative, coordinated, automated and shared data distribution framework. A positive feedback loop developed once the initial state and territory custodians began engaging and uploading their data for user discovery. Broad public interest in the data began growing exponentially, causing more custodians to engage and making ever larger volumes of data available for download, thereby increasing usage further. ELVIS is serving an ever-expanding cross-section of business, government, community, educational and research sectors, with the number of data orders growing over the past year alone by 300% to 5000 data orders per month and is projected to deliver over 65,000 orders in 2018/19. Recent user survey results clearly indicate the direct cost benefit to all users in having ready access to ELVIS elevation data is an average of at least AU$2000 per download. This would equate to a total AU$120 million benefit to the Australian economy in the current financial year. At a total system maintenance cost of approximately $70,000AU per year, ELVIS has realized significant cost savings for collaborators due to its shared infrastructure, but more importantly it provides a capability to enable 'Big Data' discoverability and access; a challenge all data custodians have faced. ELVIS is not only a system for enabling data management, discovery and dissemination of lidar and DEM data; the system also brings together a community containing all the Australian elevation data custodians. This community has a common agenda to improve the consistent application of standards for data collection, whilst promoting future collection plans with the goal of enhanced collaboration.

LIDAR LEADERS

Outstanding Enterprise Achievement

ENTERPRISE FINALIST Woolpert

Woolpert has provided a high-level of contributions to the lidar industry in service, management and development since the technology was introduced. An early adopter pioneer of lidar technologies, Woolpert has set many industry precedents. Examples of their work with federal agencies, programs and applications include:

- **USGS:** Woolpert has acquired and processed over 350,000 square miles of lidar data in support of 3DEP at dozens of locations both CONUS and OCONUS, including statewide programs; and evaluated lidar technologies for 3DEP.
- **BuckEye:** Woolpert evaluated and improved data workflow, and led the design, integration and testing of its next-generation airborne sensor.
- **USACE/JALBTCX:** Woolpert is supporting bathymetric and topographic lidar acquisition at CONUS and OCONUS locations and with simultaneous airborne operations to vastly increase data acquisition rates.
- **DARPA:** Woolpert performed data fusion of imagery, airborne and mobile lidar data acquired by Woolpert for the defense agency. The imagery was used to colorize the blended lidar point cloud. The fused data set was the basis for one of the first semi-automated feature extraction projects.

WOOLPERT

Woolpert also:

- Acquired and processed lidar data to support security for 2 presidential inaugurations.
- Acquired and processed lidar data to support the 133 Urban Area Elevation Data program.
- Acquires and processes airborne, mobile and terrestrial lidar data for many DOTs.
- Rapidly acquires and processes lidar data for federal agencies for post-storm emergency response.
- Conducted the first large lidar projects in Florida.
- Conducted the first inland riverine topographic-bathymetric project in Washington (2004).
- Conducted the first countywide lidar with topographic mapping project in the nation in Alabama (2005).
- Developed and conducted the first statewide lidar program of its kind in Ohio (2006).
- Acquired and processed lidar data in support of the Panama Canal expansion (2007).
- Conducted the largest mobile mapping project at the time, collecting over 3,500 linear miles in Indianapolis (2010).
- Developed a novel SPL and side-stepping RGB camera co-collection mapping system for the Army in 2013, meeting wide-area mapping requirements and penetrating dense vegetative canopy.
- Was contracted by the USGS to evaluate Geiger mode and SPL for 3DEP, leading to USGS considering these viable.
- Conducted the largest commercial SPL acquisition in North America in 2017.
- Continues to develop automated tools to extract intelligent data from lidar point clouds.
- Woolpert's Dr. Qassim Abdullah, Jeff Lovin and Layton Hobbs served on ILMF and ASPRS advisory boards. The firm owns and operates a fleet of aircraft, vehicles and lidar sensors, and trains clients to make better use of lidar data.

ICESat-2

ICE, CLOUD, AND LAND ELEVATION SATELLITE-2

ENTERPRISE FINALIST ATLAS development team at NASA Goddard Space Flight Center (NASA ICESat 2 Mission—NASA Goddard Space Flight Center)

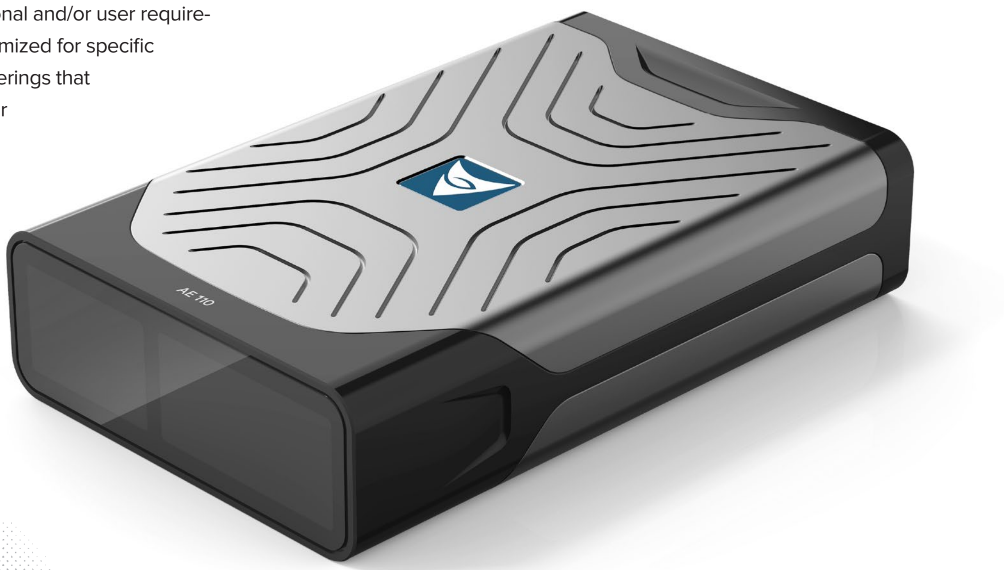
The most capable and complex lidar ever flown, ATLAS was launched in September 2018. ATLAS (Advanced Topographic Laser Altimeter System) is the sole instrument flying on the NASA ICESat-2 satellite mission, part of NASA's Earth Observing System. The ICESat-2 mission will provide scientists with height measurements to create a global portrait of Earth's 3rd dimension, gathering data that can precisely track changes of terrain including glaciers, sea ice, forests and more. ATLAS uses six beams to range to the Earth's surface from a 500 Km orbit, at a repetition rate of 10 KHz, and the detection system operates in single photon lidar mode—a first for space instruments. In order to accommodate the large range of surface reflectivities three of the beams are of stronger intensity than the other three, and each channel is detected by multiple pixels in respective photomultipliers. ATLAS timing boards are quite similar to those used in the airborne version of the same class of instrument. Given the temperature variations that the system encounters through the orbit, and the narrow field of view of the telescope, ATLAS required a sophisticated active alignment system to keep the laser beams at the center of the receiver telescope boresight. Furthermore, in order to produce accurate geolocation of the spots on the ground, ATLAS includes a laser reference sensor, which tracks for every shot, the pointing of the lasers with respect to the stars. This milestone, of passing performance testing and integration into the spacecraft, brings celebration to a decade of work. This enterprising effort would not have been possible without the unique skills and incredible dedication of the ATLAS development team.

LIDAR LEADERS

Outstanding Innovation in Lidar

INNOVATION FINALIST AEye for the AE110 Artificial Perception System

The AE110 is a solid state artificial perception system that takes a disruptive approach to vehicle perception. Its distributed system fuses solid-state agile lidar with a low-light HD camera, then integrates artificial intelligence in order to capture more intelligent information with less data. AEye's patented iDAR™ technology uniquely brings together software definability, artificial intelligence, and smart, agile sensors to dynamically assess and prioritize what's most relevant in a scene, then process this data at the edge. Many of the unique, high-performance features of the AE110 are designed to be software definable by perception engineers utilizing the AE110 API. There are four feedback loops built into the system, enabling fine dynamic software control at multiple levels, including software-defined scan modes that allow the AE110 to be "situationally aware" and to dynamically combine scan patterns as appropriate for any driving condition or environment. These can be implemented according to situational and/or user requirements and include scan patterns optimized for specific driving conditions. Unlike existing offerings that indiscriminately and separately gather massive amounts of information about the environment, then pass the siloed information to the CPU, where precious power and time are used for fusion, alignment, decimation and processing, causing latency, only AEye infuses agile targeting and intelligence into the data collection process, enabling the capture of better quality information, using less data, for quicker reaction times. By using a distributed, software definable system that embeds computer vision with machine and deep learning on its lidar, AEye puts perception engineers in control, and brings intelligence to the sensor layer—enabling the type of precision and real-time perception critical to the rollout of safe autonomous vehicle systems.



INNOVATION FINALIST ASTRALiTE for the Bathymetric Lidar System for UAS

Bathymetric lidar from an unmanned aircraft system has been a challenging technology to develop and commercialize. While a few companies have developed a single pulse bathymetric lidar, ASTRALiTe has recently developed first scanning topo-bathymetric lidar system. This is a significant advance on prior unmanned, and manned aircraft-based systems. This milestone demonstrated a more versatile scanning instrument that enables 2-D imagery of the underwater scene, and yet meets the size, weight and power requirements for UAS deployment. The ASTRALiTe lidar provides highly accurate measurements of water depth with 1-centimeter depth resolution. This 1-cm depth resolution means the technology can be used to image shallow water as well as deeper waters. It also means the transition from land to water can be measured and identified accurately. ASTRALiTe's scanning lidar capability can be used for both small scale and larger scale survey and mapping projects of streams, rivers, ponds, lakes, and coastal environments. This advancement over prior technologies enables new applications in underwater infrastructure inspection, military logistics, natural disaster assessment and recovery, risk assessment for industrial retention ponds, and water resource management.

INNOVATION FINALIST Velodyne LiDAR for the VLS 128

Velodyne LiDAR's VLS-128 sensor was designed to fulfill the requirements of both traditional automotive industry OEMs and new technology entrants. Their requirements include a high-performance sensor that can be produced in volumes and at the scale needed by the auto industry. Introduced in March 2018, Velodyne LiDAR's VLS-128 is featured on Voyage's autonomous vehicles in use at retirement communities in California and Florida. The senior citizen population is seen as one of the early adopters and greatest beneficiaries from autonomous driving that provides them safe mobility on demand. The VLS-128 sensor will soon be seen on a range of other deployments in Europe, North America, Japan and China. Lidar sensors are required for safe autonomous driving because they provide the precision perception capabilities that enhance a vehicle's ability to see in ways that other types of sensors cannot. For fully autonomous driving, you need a vehicle to perceive the world around it in all conditions with a fine level of granularity. For highway driving, the vehicle needs to see far away. The VLS-128 provides real-time 3D data up to 0.1-degree vertical and horizontal resolution with up to 300-meter range and 360° surround view. The VLS-128 provides the range, resolution and accuracy required by the most advanced autonomous vehicle programs in the world. It achieves the longest range, highest resolution and widest field of view—the trifecta of lidar specifications.

Outstanding University Achievement in Lidar

Universities included in this year's process include:

Ferris State University

The Surveying Program at Ferris State University was established in 1958. It is the largest undergraduate Surveying engineering program in the Midwest and one of the largest in the U.S. The program offers the following: BS in Surveying Engineering, AAS in Surveying Technology, and certificates in Surveying, GIS, and Hydrographic mapping. The Bachelor of Science in Surveying Engineering is approved and recognized by the Michigan State Board of Licensing for Professional Surveyors and is also accredited by ABET. Students graduating from the bachelor's program after appropriate work experience are eligible to take the professional surveyor and the professional engineer examinations. The Surveying Engineering Department has educated surveyors for more than fifty years and has provided diverse employment opportunities with large and small private surveying and mapping firms; federal, state and local governmental agencies globally. The program offers over $20,000 in annual scholarships.

Hasso Plattner Institute

Today, landscapes, cities, and infrastructure networks are commonly captured using lidar or image-based remote sensing technologies at regular intervals. The resulting 3D point clouds are digital twins of the captured surfaces and provide valuable information. Consequently, 3D point clouds have become essential for a growing number of applications, such as urban planning, environmental monitoring, and disaster management. The data acquisition workflow itself, whether by air (e.g., plane, helicopter, UAV), sea (e.g., boat), or land (e.g., car, train, stationary scanners) is well established and generates highly detailed 3D point clouds with several terabytes of data. However, the management, analysis and presentation of those data sets still pose challenges because existing GIS are often limited by processing strategies and storage capabilities that generally do not scale for massive 3D point clouds. We present a web portal designed to manage, analyze, and distribute large-scale 3D point clouds. It provides efficient means for an interactive and collaborative exploration and inspection on client devices with different computing capabilities. Point-based rendering techniques and post-processing effects are provided to enable task-specific and data-specific filtering and highlighting. A set of interaction techniques allows users to collaboratively work with the data, e.g., by measuring, annotating, or triggering analytics tasks for arbitrary data subsets. These tasks include for example: (1) Classification and change detection for urban areas captured with airborne lidar or image-matching. (2) Classification and asset detection for 3D point clouds from mobile mapping. (3) Analytics for 3D point clouds from UAVs to monitor vegetation and construction sites.

University of Houston

The NCALM (National Center for Airborne Laser Mapping) is based at the University of Houston and is operated in partnership with the University of California, Berkeley. The center is supported by the National Science Foundation and is associated with the multi-disciplinary Geosensing Systems Engineering & Sciences graduate program at the University of Houston. The mission of NCALM is to:

1. Provide research-quality airborne light detection and ranging (lidar) observations to the scientific community.
2. Advance the state of the art in airborne laser mapping.
3. Train and educate graduate students with knowledge of airborne mapping to meet the needs of academic institutions, government agencies, and private industry.

University of Kentucky

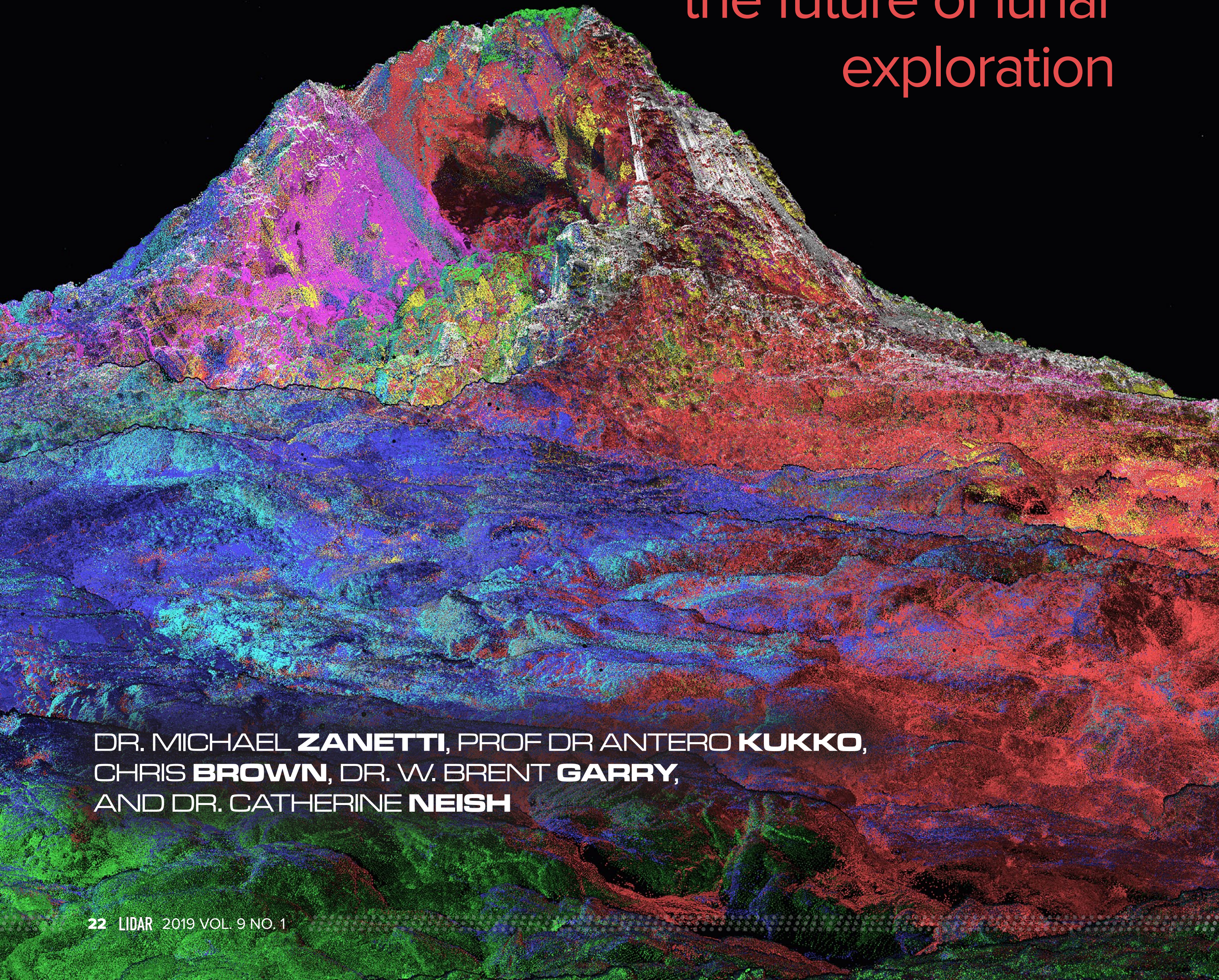
Many safety hazards on our roadways that cause accidents are often imperceptible and difficult to measure. The Kentucky Transportation Center at the University of Kentucky has discovered several innovative applications for using mobile lidar to mitigate such highway safety hazards. One such application has been in evaluating areas known for accidents during wet weather events. According to data from the Kentucky State Police crash database, 20% of all highway accidents in the past 5 years occurred during wet weather events and over 1800 accidents cited "water standing or moving" as a contributing factor. "Water standing or moving" can be deciphered as an area where the pavement design is inadequate during intense rainfall events, which may create conditions known to cause hydroplaning. Through the use of our mobile mapping system we are able to re-create a highly detailed roadway surface allowing us to analyze slope and drainage patterns that could be problematic for vehicles during such rainfall events. Another application of mobile lidar to improve highway safety has been in locating and quantifying lane differential settlement on concrete pavements. Substantial lane differential settlement poses a hazard to vehicles, and particularly to motorcyclists, when changing lanes. A scan of the affected roadway with our mobile mapping system, along with our innovative processing techniques, allows us to isolate these areas of differential settlement and provide the location and approximate quantities of settlement to assist in remediation efforts.

University of Maryland, College Park

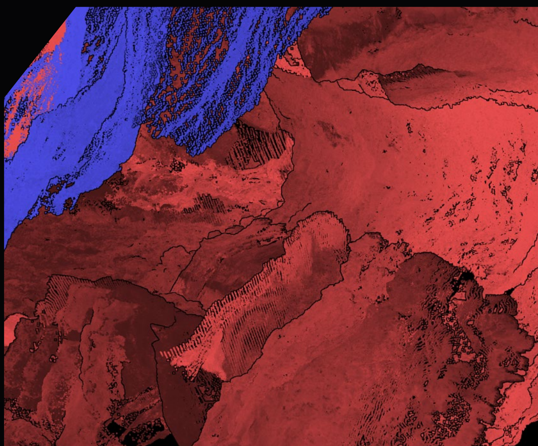
University of Maryland's Master of Professional Studies & Graduate Certificate Programs in GIS and Geospatial Intelligence are dedicated to providing the most up-to-date training on geospatial technology, theory, and applications.

FINESSEing Lunar Exploration

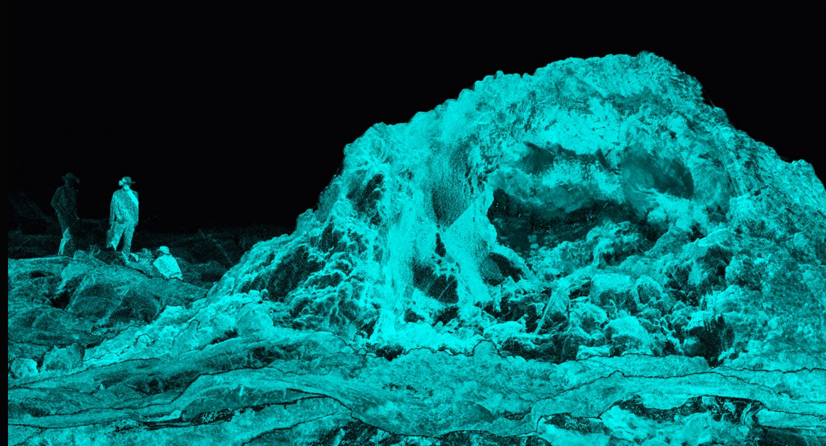
A role for Lidar in the future of lunar exploration



DR. MICHAEL **ZANETTI**, PROF DR ANTERO **KUKKO**, CHRIS **BROWN**, DR. W. BRENT **GARRY**, AND DR. CATHERINE **NEISH**

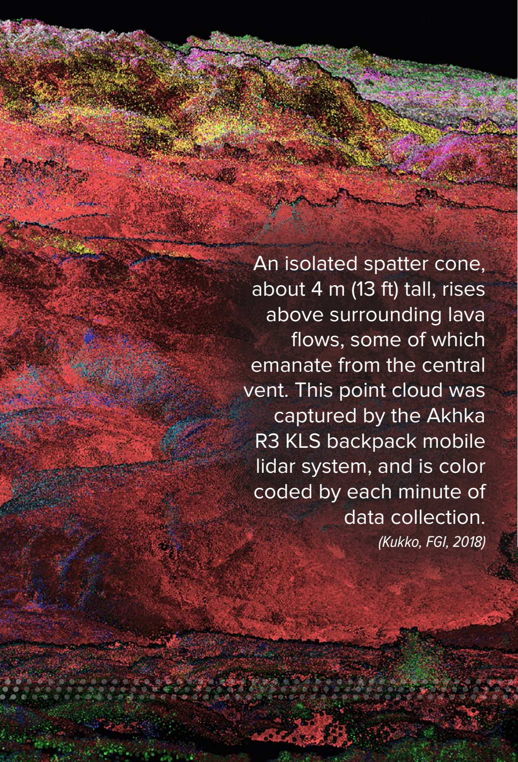


Additional scans from our catalog of volcanic features including lava tubes and flows.



Field team members are gathered to the left of a small, isolated spatter cone in the far reaches of the lava field. Two hours of hiking were needed to access this site, but only ~15 minutes to capture it.

KLS point cloud colored by intensity, Kukko, FGI, 2018



An isolated spatter cone, about 4 m (13 ft) tall, rises above surrounding lava flows, some of which emanate from the central vent. This point cloud was captured by the Akhka R3 KLS backpack mobile lidar system, and is color coded by each minute of data collection.

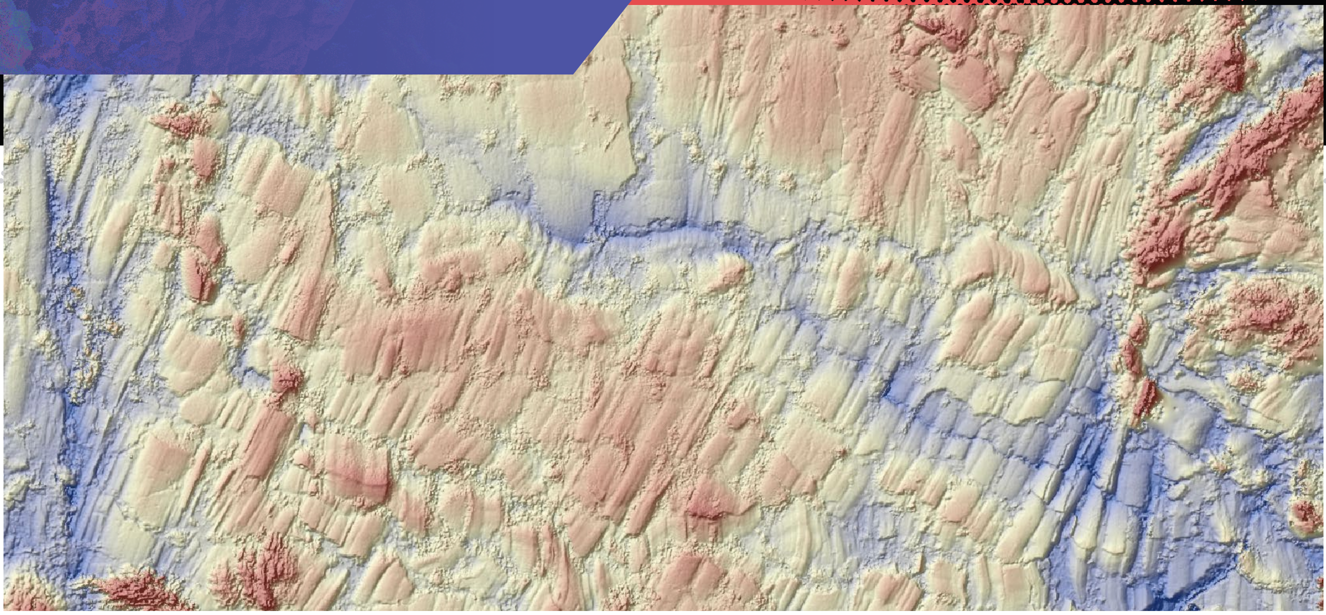
(Kukko, FGI, 2018)

Early explorers set off into the jungle, or the desert, or some exotic land with the intent to learn as much as they could and share that information upon their return. If the place was interesting enough, or offered some resource of value, these early accounts provided the framework for future exploration and eventual settlement. The idea of returning to that place was likely never too far off in the mind of the explorer, because it was relatively feasible to return and explore further.

Now consider the task of exploring the surface other places in our Solar System, like the Moon, Mars, and beyond. The immense cost of the initial exploration is such that it makes it very unlikely that a chosen landing site will be re-visited, unless there is overwhelming cause for return. After all, with so much of an entire planet to visit, why go back to where you've already been?

So the question for the folks like us who think about this kind of thing is: How do you maximize exploration and discovery? And, how do you do this with limitations on mobility, time, and cost? What is the strategic knowledge needed to answer the question of *how* to explore other planets?

The simple answer to these questions is to use comparable places on Earth to practice our exploration strategies. A previous issue of this magazine discussed how we use lidar at comparative planetary analog sites in the high arctic to understand climate change and the geomorphology of Mars. In this piece, we discuss how tripod (TLS) and mobile (KLS) lidar instruments were used as part of NASA's Solar System Exploration Research Virtual Institute (SSERVI) Field Investigations to Enable



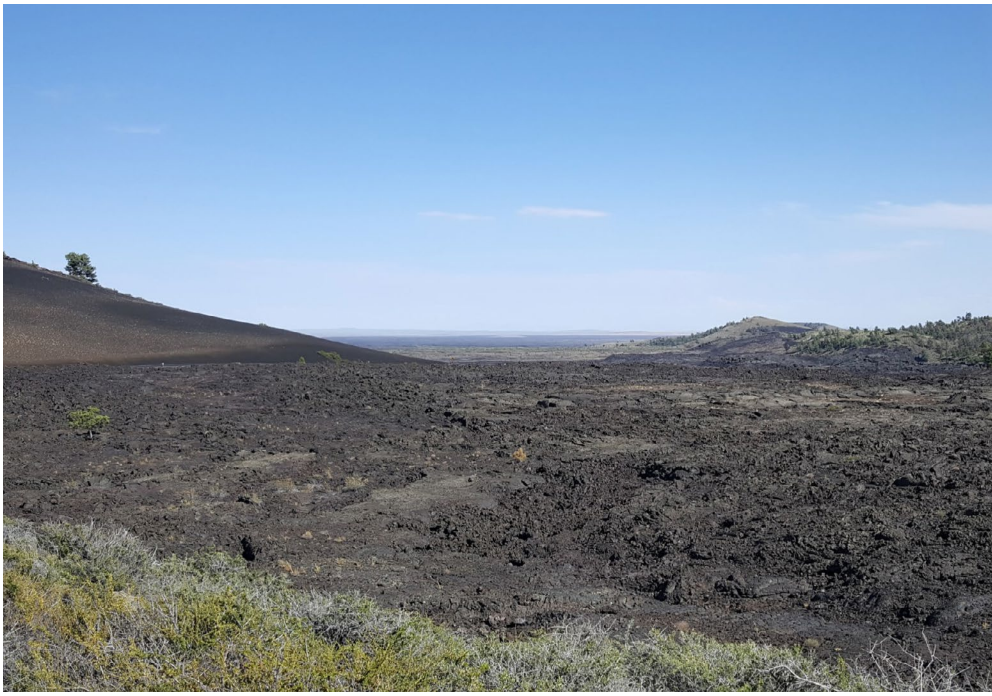
Solar System Science and Exploration (FINESSE) program. The FINESSE program is a consortium of more than 30 research scientists, professors, and students whose goal is to generate strategic knowledge in preparation for the human and robotic exploration of the Moon, near-Earth asteroids (NEAs) and and the Martian moons Phobos and Deimos. To accomplish this, over the last 5 years FINESSE scientists have explored the Craters of the Moon National Monument and Preserve (CRMO) with the objective of determining the ideal suite of instruments, observation and sampling strategies needed to maximize scientific exploration.

Associated with the main project goals, those of us interested in lidar surveying want to show how different lidar instruments and surveying techniques can, and should, be considered as integral tools in the future exploration of planets. Our work shows that lidar data delivers maps for navigation, topography and morphology, and terrain roughness, as well as provides important context for other scientific investigations.

"A mass of 'Black Vomit'"

Craters of the Moon National Monument and Preserve is an enormous region (~1900 km^2, ~720 mi^2) of the Snake River Plain in southern Idaho. The park features some of the best preserved and youngest basaltic lava flows (as recently as ~2000 years ago) in the continental United States. The park is dominated by extensive lava flows, most emanating from a series of fissures and rifts related to basin-and-range tectonics after the North American plate migrated southwestward over the mantle hotspot that now exists under Yellowstone National Park. During the first mapping expedition of the area in the 1830's, Capt. Benjamin Bonneville

The KLS mobile lidar system provides ultra-high resolution (~1 cm/pixel), enough to discern "rifts" and "micro-plates" formed on the surface of the lava as it oozed and flowed. Image is 35 m (115 ft) wide, with total vertical relief of ~50 cm (1.6 ft).

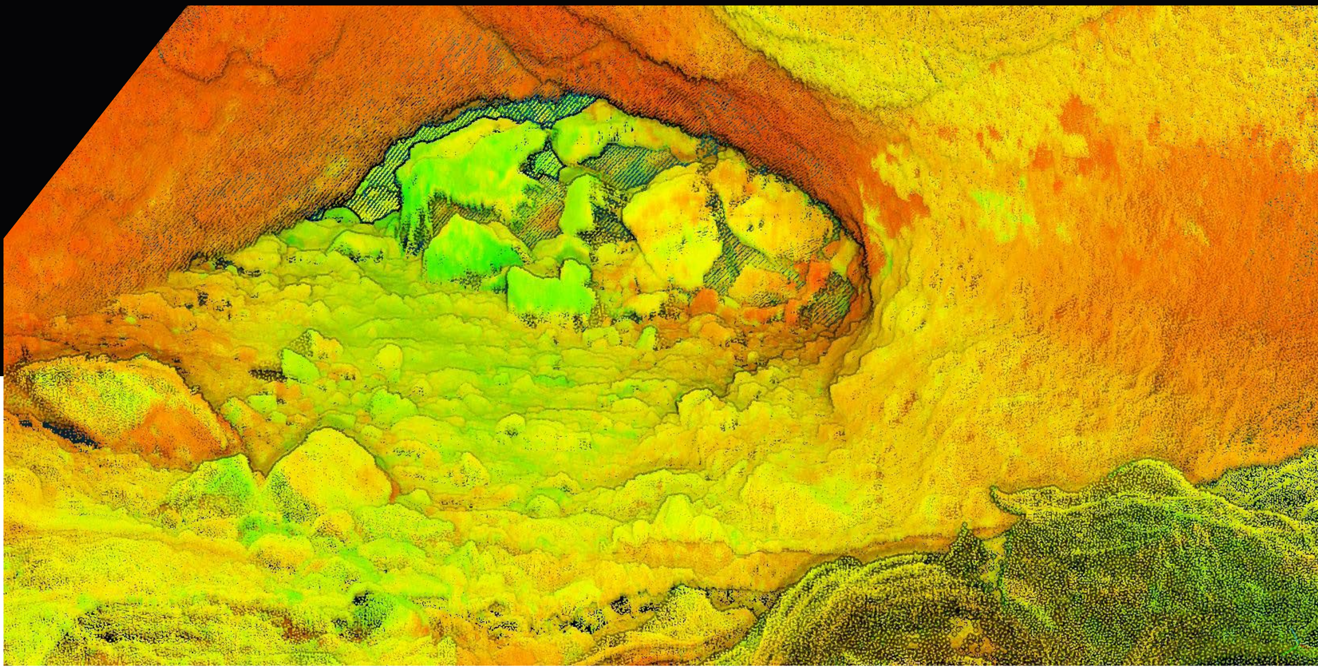


A panoramic view of an area of spatter cones in Craters of the Moon National Monument, Idaho. These mini-volcanoes rise 20 m (65 ft) or more above the expansive lava flows within the park.
Zanetti

described it as “a desolate and awful waste; where no grass grows nor water runs, and where nothing is to be seen but lava”. In the 1860’s, when settlers in wagon trains skirted along its margins while travelling Goodale’s Cutoff of the Oregon Trail, Julius Merrill described the area as “a mass of ‘*black vomit*.’” Superficially, these descriptions are correct, but fail to capture the eerie beauty and catastrophic violence the area has undergone. Individual lava flows shimmer in iridescent blues and greens, due to oxidation of trace titanium and magnetite. The lava fields glisten in the heat, and the attractiveness of the terrain changes depending on the dehydration level of the observer. Huge cinder cones, formed by fire-fountain lavas typical of Hawai’i, rise above the Great Rift in the central part of the park. Overall, the National Monument shares many similarities to the ‘magnificent desolation’ that Buzz Aldrin described while walking on the Moon during Apollo 11. Indeed, the park was used by Apollo 14 astronauts for geologic training exercises in August, 1969 shortly after Buzz’s return from the Moon.

Exploring with Lidar

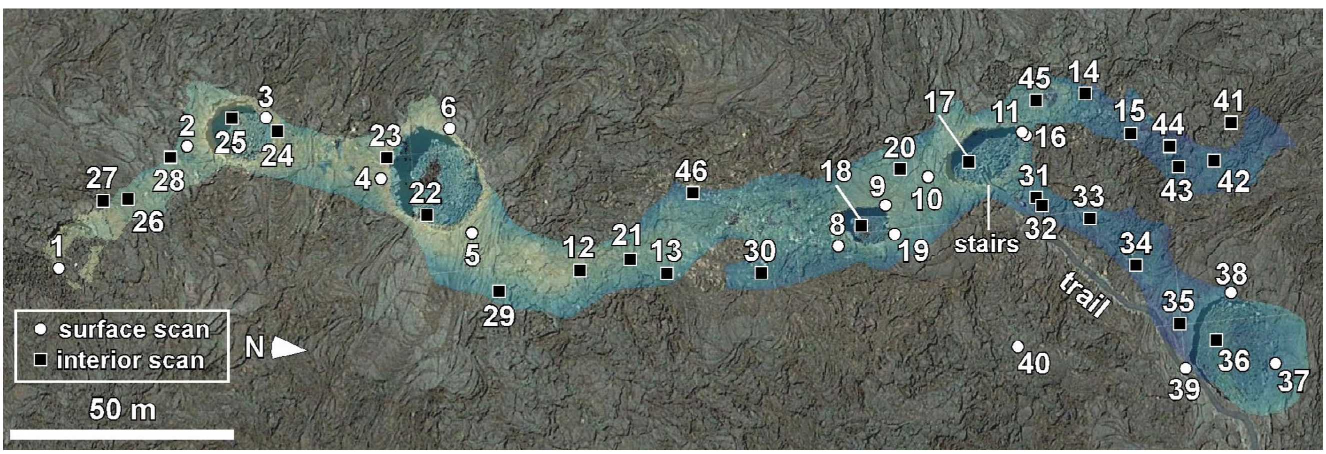
The two main roles for lidar surveying in exploration are to provide high-accuracy topographic maps and to provide vital context for follow-on scientific measurements. As a stand-alone product, lidar point clouds and post-processed raster digital elevation models (DEMs) are essential for terrain mapping, understanding the morphology and morphometry of features, and quantifying the roughness of the terrain for hazard studies and understanding radar remote-sensing. Within the context of our lava flow investigations, lidar serves as an indispensable base map layer for overlays of visible, hyperspectral, and geophysical imagery and data. lidar provides precise and accurate spatial understanding of where samples came from, how they were oriented, and their geologic context. The TLS and KLS systems also proved indispensable for understanding geophysical data from gravity and magnetometer instruments (see sidebar). The ultra-high resolution DEMs from the KLS instrument have also provided a link between satellite and airborne remote-sensing data, allowing for an unprecedented level of accuracy in quantifying surface roughness for studies of radar backscatter properties. Both TLS and KLS systems have delivered exceptionally detailed views of the morphology of different volcanic features, such that we are now just beginning to understand how to use the data to its full potential.



Oblique view looking into the mouth of the Indian Tunnel lava tube. This is point cloud data collected by the KLS and color coded by intensity.
Kukko, FGI, 2018

Technical specs of the Lidar

The lidar point clouds that were produced by our group were done using tripod-mounted TLS and kinematic mobile KLS scanning. The TLS system is a Riegl VZ-400 (RIEGL Laser Measurement Systems GmbH, Austria), mounted with a DSLR and Trimble R8 DGPS (Trimble Inc., USA). Point clouds were processed and matched in RiSCAN Pro 2.3. Our KLS system is the Akhka-R3 Kinematic lidar Scanner (KLS), a custom-made backpack-mounted mobile lidar scanner developed at the Finnish Geospatial Research Institute. The KLS uses a Riegl VUX-1HA profiling laser scanner coupled to a NovAtel UIMU-LCI inertial measurement unit and a Flexpak-6 GNSS receiver coupled with 703-GGG antenna (NovAtel Inc., Canada). Areas of interest were walked (or stumbled based on the terrain) and scanned at ~150 – 250 Hz profiling and 500 – 1000 kHz pulse repetition frequencies and maximum ranging from 150 m (1000kHz) to 300 m (500kHz). Precise point processing (PPP) methods using NovAtel's Waypoint Inertial Explorer 8.6 and 5Hz DGPS data from a Trimble R10 GNSS base station were carried out to solve for the precise base station location



Locations of TLS tripod sites taken to completely capture the extent of the Indian Tunnel. Surface scans are white dots, interior scans are black squares.
B. Garry, NASA

Antero Kukko collects static data for the IMU and GNSS on the Akhka R3 KLS backpack lidar before venturing into the lava tubes (note the headlamp).

Chris Brown collects magnetometry data around one of the skylight openings of the Indian Tunnel. Lidar and geophysical data proved to be an exceptionally useful pairing.

Brown

with a ~1-2 km (~1 mile) baseline at each site. The base station data was then used for calculating the solution and 200Hz kinematic platform trajectories for point cloud generation. KLS field data was stored in 1 minute blocks and processed and matched using Riegl's proprietary software and TerraSolid (TerraSolid Oy, Finland) products. The absolute lack of overhead vegetation at the site permitted full satellite coverage, with typically more than 17 GPS and GNSS satellites locked. Trajectories and inherited point cloud accuracy of the KLS scans were on the order of 1 – 2 cm. However, even this small amount of mismatch of the data was deemed detrimental to capturing very fine scale details of the lava surfaces. Therefore an

additional matching steps were taken to remove as much of the discrepancies as possible. Given the millimeter-scale ranging precision and beam spot size of 0.5. mrad (25 mm at 50 m range) from the VUX-1HA and the tactical grade FOG IMU, the KLS has captured surface details at an extraordinary level, often better than 1 cm/pixel raster image resolution.

TLS and KLS systems each serve different purposes. Our TLS system was best suited for areas of limited GPS coverage, and excelled in the subterranean mapping of lava tubes. However TLS scanning proved time consuming for surface scans, requiring multiple scans to minimize obstruction shadows. The KLS system was advantageous for rapidly covering large surface areas (acres within hours) while also minimizing shadows by easily maneuvering around objects. The trade-off with using a KLS system is a more complicated and error-prone processing protocol (dependent mostly on satellite coverage) compared with TLS data processing.

Lidar Scans of Volcanic Terrains

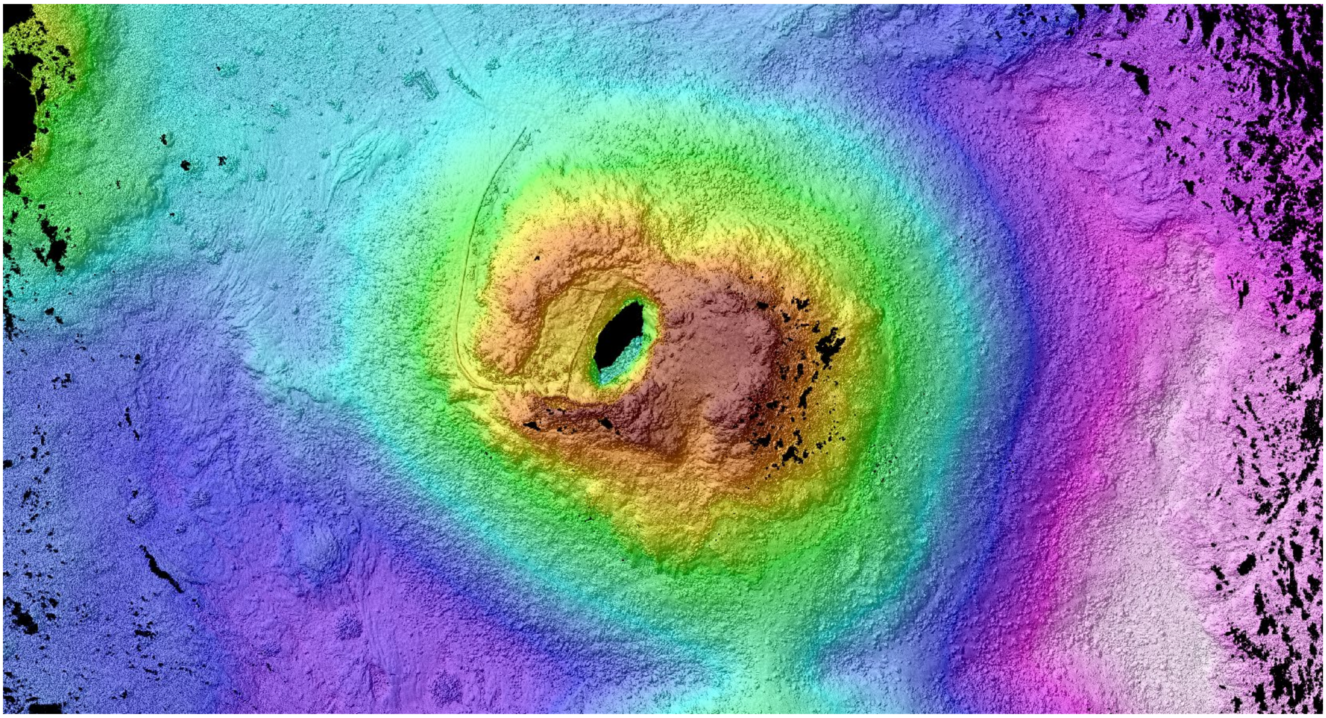
In addition to providing context for science investigations, we have begun cataloging the morphology of small-scale volcanic features in unprecedented detail. The data we show here is a small collection of the more than 10 acres scanned and 500 GB of data collected. Some of our scanning focused on mapping common hiking trails to support 3D visualizations for the park, while other features were scanned to understand the detailed geologic evolution of how lava flows are emplaced.

The lavas of Craters of the Moon are nearly all “pahoehoe” style, forming undulating and ropy masses as the lava oozes and flows across the surface. When flowing smoothly, the lava mimics water-rivers (albeit of molten rock) forming eddies, turbulent streams, and “lava-falls”. Sometimes the eruption style changes and becomes more prodigious, ripping off the sides of massive cinder cone volcanoes and rafting huge chucks of Earth miles away from their starting points. The results are massive slabs and rubble piles of once smoothly emplaced flows.

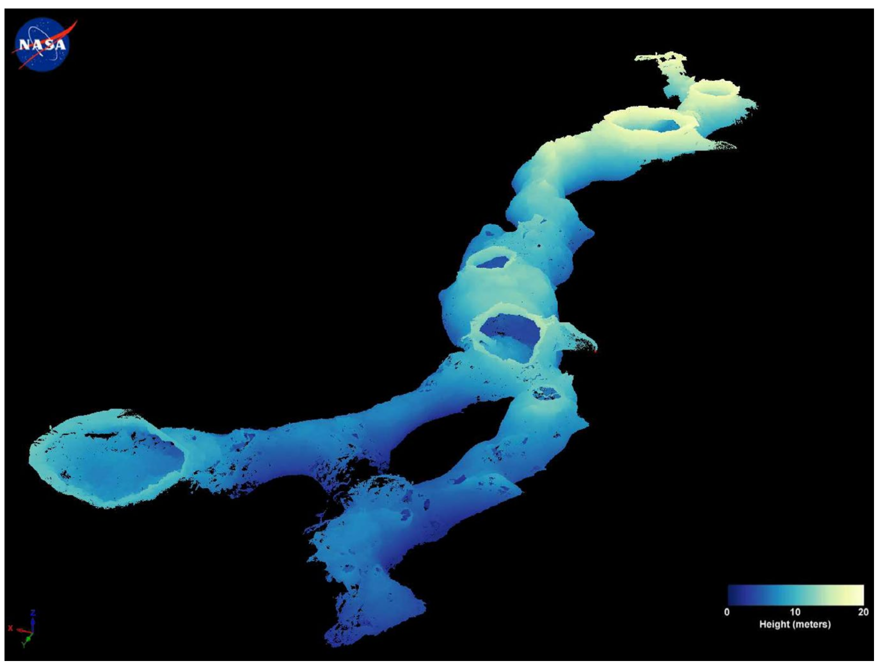
Experiments using 200 kgs of remelted basalt were done to simulate lava flow morphology and spatter cone development using a large furnace at Syracuse University (lavaproject.syr.edu).

Zanetti

A frequent feature within the endless lava-flows in the park landscape are spatter cones. Spatter cones are made by repeated explosions of ‘blobs’ of molten lava that weld together forming relatively small, steep-sided mounds around a central vent. FINESSE team members have spent significant effort trying to understand the temperature and chemical/geologic conditions necessary for lava to weld itself into huge mounds (contrary to expectation, small volumes of lava can rapidly quench to glass preventing welding). Collaborative experiments with the Syracuse University Lava Project have gone as far as ‘manufacturing’ lava blobs to determine how they stick together.



Map view of a DEM created using the KLS scanner of the tourist accessible spatter cone in the park (shown above). The 20 m high dome was created by innumerable "blobs" of lava that exploded from the central vent.
A. Kukko and M. Zanetti



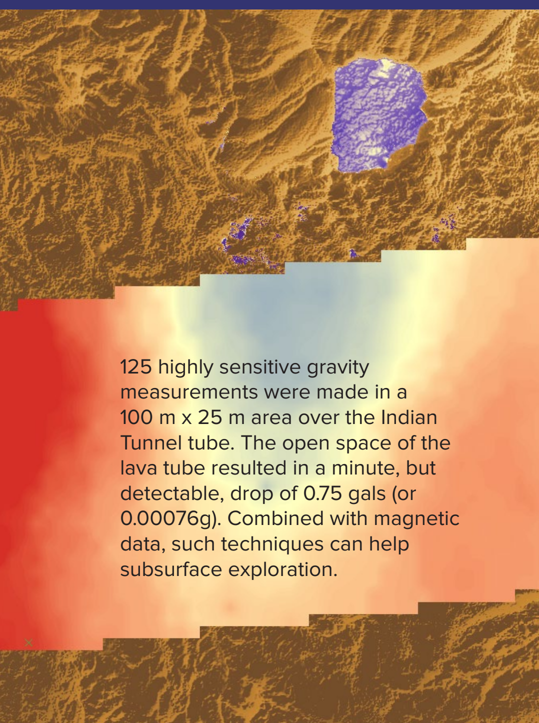
Subterranean map of the Indian Tunnel lava tube as mapped by TLS lidar. Approximately 1 billion points were collected at ~50 TLS sites covering the entirety of the 250 m long tube.
B. Garry, NASA

Surveying Lava Tubes

Within Craters of the Moon National Park there are a number of tubes large enough to walk through. The largest and most popular is the Indian Tunnel, a ~250 m (~820 ft) long lava tube cave that is up to 22 m (72 ft) wide and 12 m (40 ft) high. Lava tubes are the remnants of once molten lava rivers flowing through self-made tunnel systems, appearing similar to a city subway system. The top portion of the lava flowing in the channel can cool and solidify, leaving a roof over the still flowing lava stream. When the lava drains a cave remains, and many times the roof is stable enough to support subsequent lava flows over the top of the cave. Many times these cavernous conduits remain hidden from view, but can be found and accessed through collapse pits that expose the interior chambers. Indian Tunnel is accessible by a few of these pits, but

Geophysics applied to Lava Tubes

Gravity and magnetic surveys are geophysical tools used to image the interior of the Earth. These tools are effective at mapping geologic environments we cannot see. Some applications include mineral exploration, oil & gas exploration, structural mapping, utility location and, in our case, cave/lava tube detection. During August 2017 gravity and magnetic surveys were conducted over Indian Tunnel lava tube at COTM by a team from Carleton University. The purpose of the surveys was to test the effectiveness of these methods for lava tube detection.



125 highly sensitive gravity measurements were made in a 100 m x 25 m area over the Indian Tunnel tube. The open space of the lava tube resulted in a minute, but detectable, drop of 0.75 gals (or 0.00076g). Combined with magnetic data, such techniques can help subsurface exploration.

Gravity surveys measure relative changes in the local gravity field which is partially dependent on subsurface density—the less dense a geologic target is, the weaker the local gravity field should be. In terms of lava tube detection, the density contrast between the void tube and the solid host-rock creates a measurable contrast in the local gravity field. Gravimeters are very sensitive instruments, and great care must be taken when recording data. The gravimeter must be carefully set-up and levelled at each reading station. Due to the complex nature of the Earth's gravity field, numerous corrections must be made to the data to separate the signal from the noise. Using high-resolution lidar data to make topographic corrections for the gravity data increases the reliability of the data.

Magnetic surveys map the subsurface distribution of magnetic minerals. Often this is caused by changes in the concentrations of iron in different types of rock. Interpretation of magnetic data collected on a planetary surface (the Moon during Apollo 14 and 16) or from satellites (Swarm, Mars Global Surveyor) allows scientists to make strong inferences about the composition and structure of a planetary bodies' interior. In practice at Indian Tunnel lava tube the open void of the lava tube created a locally weak magnetic field relative to the surrounding, iron-rich basalts. To collect the magnetic data, we were able to walk over the terrain while recording data. This is much simpler than stopping and setting up the instrument for each reading for the gravity survey. As with the gravity survey, mapping of Indian Tunnel was successfully completed using a magnetometer.

The survey done at the Indian Tunnel lava tube accurately measured the both the contrast in the gravity field and magnetic signature between the lava tube and the host rock. The results from the survey allowed us to define the spatial extent of Indian Tunnel from the surface, with the implication that these methods could be used to determine if underground passages exist, and they could be of use for future surface exploration.

primarily by a rudimentary concrete staircase that terminates on a pile of jagged rocks. The shape of the tunnel is generally domed with a flat floor, which represents the final geometry of the cave when the flowing lava finally solidified, but is strewn with large piles of boulders from the fallen roof material. Indian Tunnel was sampled multiple times for geologic composition and astrobiological and cave-microbe studies, as well as with geophysical measurements of local gravity and magnetic variations.

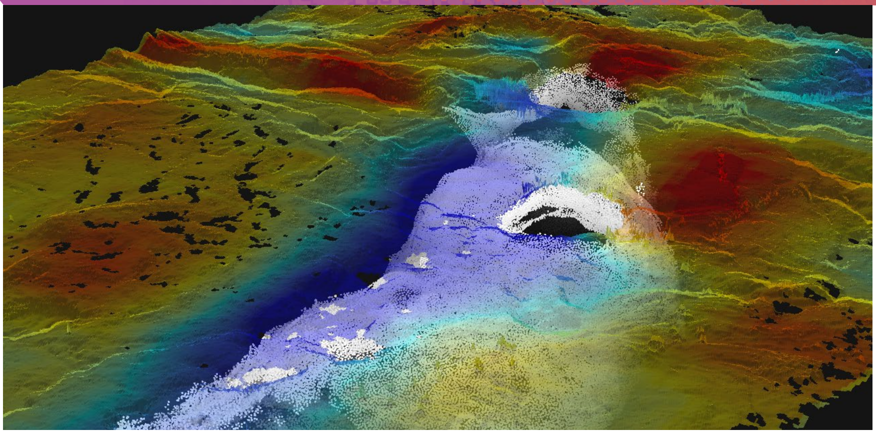
The FINESSE team was interested in Indian Tunnel because of its similarity to collapse pits (e.g. skylights) that have been observed on both the Moon and Mars. These extraterrestrial caves might prove to be effective bases for human surface operations because they offer relative shelter from harmful radiation and micro-meteorite bombardment, or as locations where extant life on Mars may be found (thus the microbial studies of cave-dwelling species adaptations). If deployed, a planetary lidar system could help investigate if there is an interior from the rim of the pit, determine accessibility, and image the interior in limited light conditions.

Lidar exploration of Indian Tunnel was done by our group using TLS tripod scans and with the KLS system. The TLS scans were done by W. B. Garry using a Reigl VZ-400 and consisted of 50 total scans (29 interior, 21 surface) to create a point cloud of ~1 billion points. TLS scanning of the tunnel was time consuming, requiring nearly 2 full weeks over 2 field seasons to satisfactorily complete. (Dr. Garry's work as part of the FINESSE program was featured in 2017 on NationalGeographic.com).

Serendipitously, the roof collapse pits acted as skylights for GPS signals and are spaced at close enough intervals that the KLS system was also able to be used for subterranean mobile mapping testing. Using the KLS system we were able to map the entire accessible length of the tunnel in less than 20 minutes, and provide complementary coverage to the TLS surveying. Although successful as a test, mapping the cave system this quickly was treacherous with the top-heavy KLS, and post-processing the data was tedious because of GPS drop-out.

The Role of Lidar in Planetary Exploration

NASA FINESSE and other research teams are demonstrating that Lidar instrumentation should be incorporated in future landed surface robotic and human exploration of the Moon and Mars. Lidar provides ultra-high resolution mapping capabilities which are both accurate and precise. Lidar's ability to actively sense the range to targets offers improvements over traditional photogrammetry techniques. Lidar offers the combination of navigation and science enhancement from a single instrument, which, from the perspective of payload limited spacecraft, offers a significant advantage. The potential virtual reality immersion from a robotic or astronaut traverse made using a seamless and accurate lidar surface representation would provide both scientific and public engagement windfalls. Still, challenges exist for the adoption of lidar in planetary exploration. Size, weight, and power limits for robotic missions severely limit the design and potential capabilities of compact lidars to operate and survive in the harsh planetary environments. Larger, pressurized rovers used by astronauts could handle a more powerful planetary lidar system.



A portion of the combined surface and subsurface lidar data overlain by magnetometry data at the Indian Tunnel lava tube. A lower magnetic signature is seen over the tube demonstrating the effectiveness of geophysical methods for finding subsurface voids.

Cloud matching in GPS-free and natural-surface environments, even with SLAM and LOAM techniques, needs to be demonstrated to be accurate and reliable before lidar will usurp photogrammetry as the 'topography-of-vogue.' Somewhat unique to planetary exploration, point-cloud data volumes could present a barrier. With new space-based laser communications, such as the Lunar Laser Communications Relay Demonstration on the NASA LADEE mission, downlink of nearly 20 Mbps has been achieved. This may solve the problem for lunar exploration, but high data rates will remain elusive for Mars for a long time to come. Regardless, there is both the interest in, and need for, lidar in planetary exploration.

Dr. Michael Zanetti is a geologist and research scientist at NASA's Marshall Space Flight Center in Huntsville, Alabama. He participated in the FINESSE program as a post-doctoral fellow at the University of Western Ontario with Drs. Catherine Neish and Gordon Osinski. He specializes in comparative planetary geomorphology of the Earth, Moon, and Mars, with focus on the integration of ground-based lidar with satellite remote-sensing data.

Prof Dr Antero Kukko is Head of the Mobile mapping and Autonomous Driving Research Group at the Finnish Geospatial Research Institute and adjunct professor in the Department of Built Environment, Aalto University, Finland. His research focuses on the development and application of mobile/kinematic laser scanning in geosciences and engineering.

Chris Brown is a geophysicist with over a decade of experience applying airborne, ground and borehole geophysical methods to assist in the detection and characterization of various types of mineral deposits all over the world.

Dr. W. Brent Garry is Geologist at NASA's Goddard Space Flight Center in Greenbelt, Maryland, USA. He investigates volcanic terrains and lava flow emplacement processes on Earth for comparison with the Moon and Mars with a focus on geomorphology and geologic mapping.

Dr. Catherine Neish is an assistant professor of Earth Sciences at the University of Western Ontario in London, Ontario. She is an expert in the use of radar remote sensing for the understanding of the geologic evolution of the Earth and other planets. She is a collaborator on the FINESSE project, and led the Western field expeditions to COTM, with funding from the Canadian Space Agency.

The DEM Users Manual, 3rd Edition

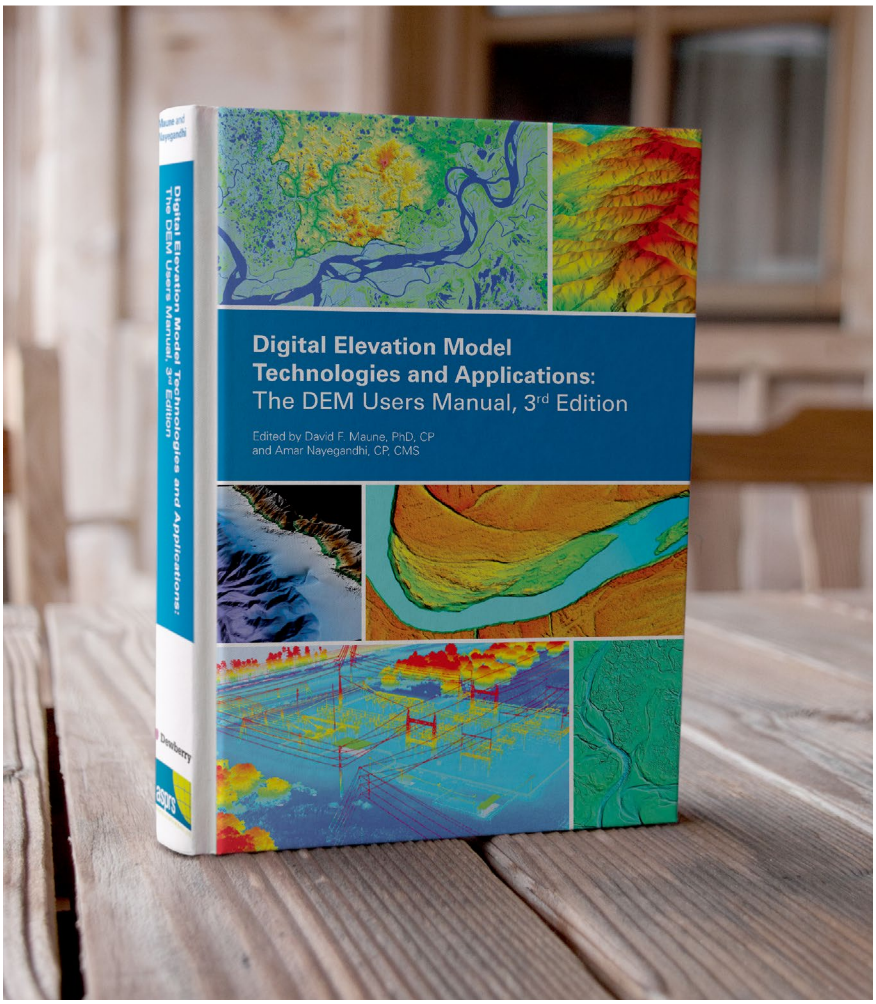


Figure 1: The DEM Users Manual, 3rd edition

BY DAVID F. **MAUNE, PHD, CP**

When *Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition* was published in 2007, topographic lidar was a new and emerging technology that had produced data according to many different specifications and formats for a relatively small portion of America. Until recently, we lacked nationwide lidar standards, guidelines and specifications, and we had no nationwide program to deliver standardized lidar data of high accuracy/resolution.

The long wait for the 3rd edition is over, and it was worth the wait. The 3rd edition (**Figure 1**) is now available in both hardcopy and e-book versions, and the co-editors (Dave Maune and Amar Nayegandhi) will be available at the ILMF/ASPRS/MAPPS conference in Denver in January 2019 to autograph copies with our signature "dream" for all DEM users—"May all your DEMs come true." Whereas prices vary for ASPRS members or non-members, students will be able to purchase copies at minimal cost ($50) because Dewberry has borne all production and printing costs, with all sales proceeds going to ASPRS to support important professional development programs.

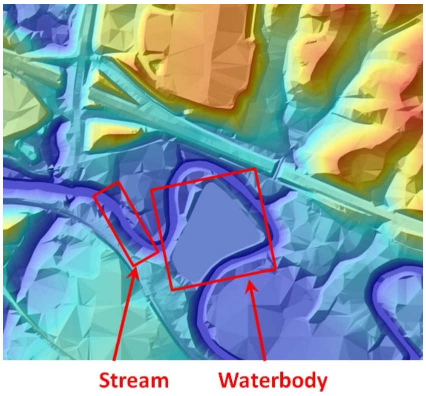


Figure 2: Traditional photogrammetric DTM.

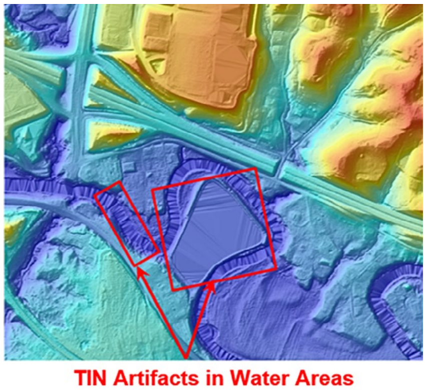


Figure 3: Pure lidar DTM without breaklines.

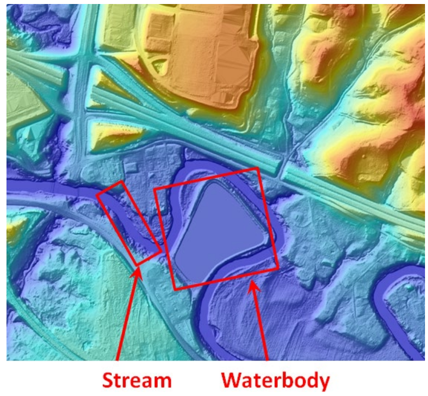


Figure 4: Hydro-flattened lidar DTM.

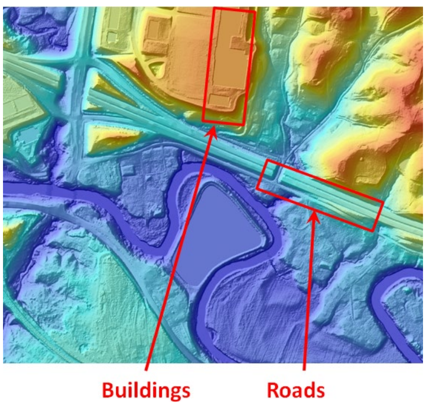


Figure 5: Lidar DTM with more breaklines.

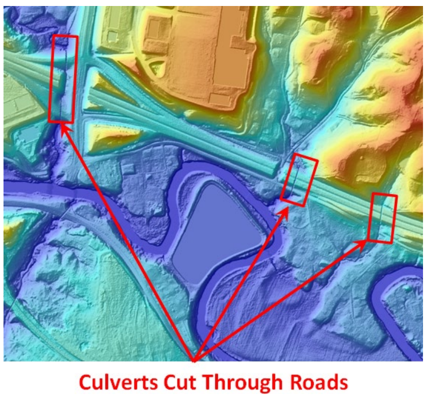


Figure 6: Hydro-enforced hydrologic surface.

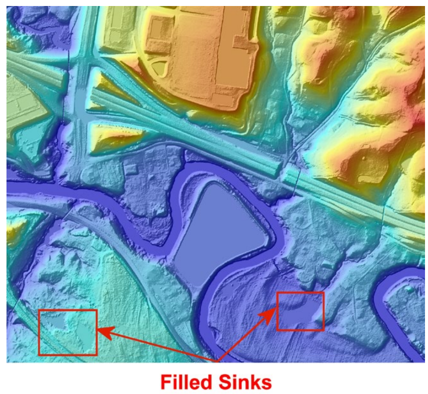


Figure 7: Hydro-conditioned hydrologic surface.

The 3rd edition includes 15 chapters and three appendices. References in the e-book version are hyperlinked for simple recovery. The chapters and appendices are:

1. Introduction to DEMs
2. Vertical Datums
3. Standards, Guidelines and Specifications
4. The National Elevation Dataset (NED)
5. The 3D Elevation Program (3DEP)
6. Photogrammetry
7. IfSAR
8. Airborne Topographic Lidar
9. Lidar Data Processing
10. Airborne Lidar Bathymetry
11. Sonar
12. Enabling Technologies
13. DEM User Applications
14. DEM User Requirements and Benefits
15. Quality Assessment of Elevation Data
    - A. Acronyms
    - B. Definitions
    - C. Sample Datasets

This book is your guide to 3-D elevation technologies, products, and applications. It will guide you through the inception and implementation of the U.S. Geological Survey's (USGS) 3D Elevation Program (3DEP) to provide not just bare earth DEMs, but a full suite of 3-D elevation products using Quality Levels (QLs) that are standardized and consistent across the U.S. and territories. 3DEP is based on the National Enhanced Elevation Assessment (NEEA), which evaluated 602 different mission-critical requirements for and benefits from enhanced elevation data of various QLs for 34 Federal agencies, all 50 states (with local and Tribal input), and 13 non-governmental organizations. The NEEA documented the highest Return on Investment from QL2 lidar for the conterminous states, Hawaii and U.S.

territories and QL5 IfSAR for Alaska. Chapters 1, 3, 5, 8, 9, 10, 13, 14 and 15 are "must read" chapters for lidar users and producers. For example, Chapter 1 (Introduction to DEMs), goes into great detail explaining the differences between hydro-conditioning, hydro-enforcement, and hydro-flattening and different forms of Digital Terrain Models (DTMs) (see **Figures 2-7**).

Chapter 3 (Standards, Guidelines and Specifications) introduces DEM users to the ASPRS Positional Accuracy Standards for Digital Geospatial Data v1.0, the ASPRS LAS Specification v1.4 and the USGS Lidar Base Specification v1.3 (2018), which are now standardized nationwide, as well as the National Ocean Service (NOS) Hydrographic Survey Specifications based on standards of the International Hydrographic Organization (IHO), which have now been adapted to bathymetric and topobathymetric lidar QLs.

Chapter 5 (The 3D Elevation Program) explains 3DEP, how it works, annual accomplishments to date, and USGS's Broad Agency Announcement (BAA) process to acquire joint funding for lidar data produced to 3DEP standards. It also explains the U.S. Interagency Elevation Inventory (USIEI), which documents available lidar data.

Chapter 8 (Airborne Topographic Lidar) explains the basic concepts of topographic lidar scanning and sensors; compares traditional linear-mode lidar with photon-sensitive and Geiger-mode lidar; boresight calibration; and the status of current lidar sensor technologies from Teledyne Optech, Leica Geosystems, Riegl, and Harris.

Chapter 9 (Lidar Data Processing) explains concepts and approaches to automated filtering of lidar point clouds to include ground and non-ground points, noise, vegetation, structures and other above-ground features; manual editing of lidar; breakline processing to include area and linear hydrographic features (see **Figure 8**) and structures; DEM processing concepts and approaches, processing techniques, incorporating breaklines, DSM processing; and other derivative products including contours.

Chapter 10 (Airborne Lidar Bathymetry) explains the basic concepts of bathymetric lidar scanning and sensors; system design; data processing including system calibration; output formats and deliverables; and the status of current sensors including SHOALS, CZMIL, LADS, Chiroptera II/HawkEye III, EAARL, VQ 820/880-G, and Titan. An example of a CZMIL topobathymetric DEM is shown at **Figure 9**.

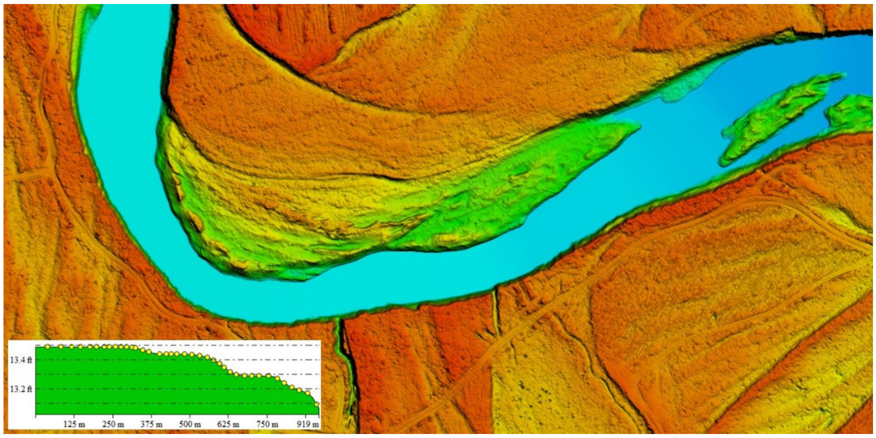


Figure 8: Example of a hydro-flattened river and profile of the downstream flow along the center of the feature. This river was flattened using a process where a centerline was collected and enforced for monotonicity and those elevations were applied to the stream banks.

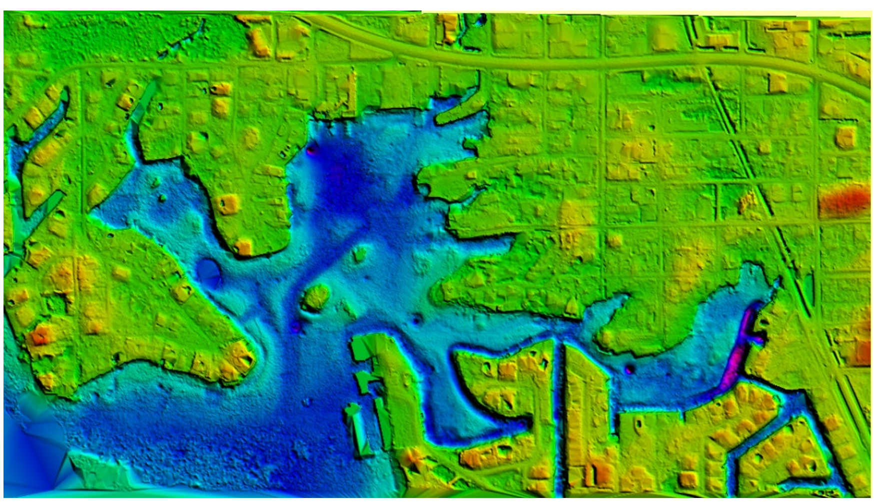


Figure 9: A topobathymetric DEM of King's Bay, Florida, produced from the CZMIL sensor with maximum depths of 18 feet.

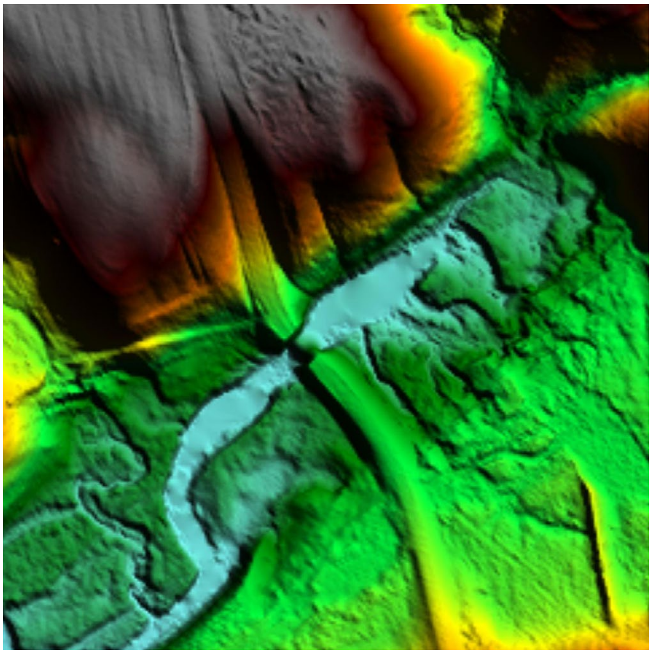


Figure 10: An interpolation artifact where a bridge has been removed from the bare-earth surface, leaving a "saddle."

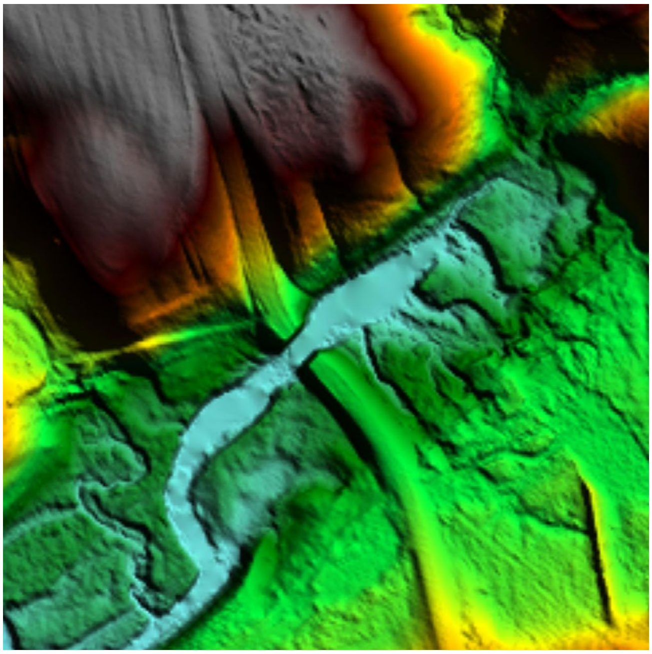


Figure 11: Breaklines were used to enforce the ground elevations beneath the bridge and remove the "saddle."

Chapter 13 (DEM User Applications) reviews how DEMs are vital for hundreds of user applications, all summarized in the NEEA's 27 major DEM Business Uses that helped justify the 3DEP. These uses also help a state or local community justify funding for their own lidar acquisition programs.

Chapter 14 (DEM User Requirements and Benefits) explains why DEM users needing lidar data should normally state their requirements for standard QL2 lidar (except in Florida where QL1 is standard), consistent with the 3DEP so as to receive standard raw and classified point cloud data, standard breaklines, standard metadata, and standard hydro-flattened, bare-earth raster DEMs—all with potential common data upgrades that do not compromise standardization and interoperability.

Chapter 15 (Quality Assessment of Elevation Data) is a 90-page tutorial with images, designed to promote consistency in delivery of elevation data acceptable for the 3DEP. This chapter reviews relevant standards, guidelines and specifications; explains procedures for testing and reporting absolute and relative accuracy; and goes into great detail in addressing various forms of qualitative assessments, to include: source data QA/QC; breakline QA/QC (breakline completeness, variance and topology); macro level reviews of DEM data; and micro level reviews of topographic and topobathymetric DEMs including hydro-flattening or hydro-enforcement, edge-matching, and bare-earth editing of buildings, bridges and artifacts. This chapter also includes procedures for QA/QC of contours and metadata. **Figure 10** shows an example of an interpolation artifact where a bridge has been removed from the bare-earth DTM, and **Figure 11** shows the corrections to such artifacts necessary for 3DEP projects.

The remaining chapters are either relevant to all DEM technologies or address alternative technologies to lidar, including photogrammetry, IfSAR, and sonar.

Appendix A is a list of acronyms and Appendix B is a summary of definitions for technical terms used in the 3rd edition. Appendix C explains where to download sample elevation datasets.

Dr. David Maune is an Associate Vice President at Dewberry Engineers Inc. where he has managed the production and/or QA/QC of over 500,000 square miles of lidar since 1997. In addition to editing all three editions of the DEM Users Manual, he authored the NEEA study that led to the 3DEP. He was the 2018 recipient of the ILMF Lidar Leader Award for Outstanding Personal Achievement.

Figure 1: HoloLens model of the ALS data collected in the vicinity of the Giant Mine underground project, used at a community meeting.

Communicating Complex Engineering Projects Using Holographic Visualization

For proper understanding, 3D projects must be communicated to stakeholders in 3D—not 2D

BY MATT **LATO**

Communicating complex engineering projects is highly intricate and complicated, especially on multidisciplinary projects that require community engagement and consultation. When projects are poorly communicated, opinions are formed and decisions made on incorrect interpretations or understanding of project details, leading to long-lasting impacts and consequences.

In today's geotechnical engineering world access to three-dimensional (3D) data is commonplace and airborne laser scanning (ALS) data is particularly prevalent. Traditional means of communicating engineering designs and the terrain in which the projects are located, however, revolve around two-dimensional (2D) maps and drawings; this is a significant challenge when communicating 3D projects—and nearly all of them are 3D.

Using 2D mediums to convey sophisticated 3D information poses a barrier to understanding by non-specialized participants, project team members or executives. Humans naturally think in 3D, not 2D, and exploiting this ability can fundamentally change how a project is understood by all stakeholders.

As stated in the *Harvard Business Review*, "There is a fundamental disconnect between the wealth of digital data available to us and the physical world in which we apply it. While reality is three-dimensional, the rich data we now have to inform our decisions and actions remains trapped on two-dimensional pages and screens."[1]

As an international applied earth science consulting firm with over 25 years of experience living the challenge of communicating 3D designs in 2D, BGC invested in developing software to bring projects to life through 3D holographic visualization. Our software, the Ada™ Platform, is usable on the Microsoft HoloLens, the world's first self-contained wearable holographic computer. Ada combines 3D terrain and survey data, engineering designs, and real-time computer graphics. It enables experts and community members to walk around and interact with a virtual version of a project from any angle or point in time. Participants can visualize key elements in 3D at scales from high level overviews to true-life "boots on the ground" viewpoints. Visualizing information such as ALS data in 3D, on a holographic visualization platform, provides project participants with an unprecedented view of a project's scope, scale, and technical details. Environments can be animated and presented at true scales to immerse the user in a project, from anywhere in the world. Furthermore, users can share environments and explore a design together.

[1] Porter, M.E. and J.E. Heppelmann, 2017. Why every organization needs an augmented reality strategy, *Harvard Business Review*, 95(6): 46-57, November-December, p. 47.

Figure 2: Stakeholders experience a HoloLens model of the Giant Mine underground remediation project.

An example project that utilized Ada is for the Giant Mine remediation. BGC worked directly with Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) and the local community to foster better understanding and collaboration for an important environmental project. Giant Mine is an abandoned gold mine with a legacy of environmental concerns. One of the most notable issues is 237,000 tons of arsenic trioxide waste stored underground. The Giant Mine Remediation Project is a 10-year, $900 million cleanup focused on managing the arsenic trioxide waste and remediating the entire site.

As the mine is more than 600 metres deep and five kilometres long with a labyrinth of underground passages, it was difficult for CIRNAC to demonstrate the scope of the remediation project and describe how the team is working to protect the environment. With Ada we were able to bring together high resolution regional ALS data (2 pts/m^2 bare earth), orthophotos, site specific vector-based information, and 3D models of the underground infrastructure into a single holographic environment (**Figure 1**).

By using Ada at community meetings, BGC and CIRNAC were able to help residents better understand the complexities of this project. "At CIRNAC, we were challenged with communicating and demonstrating the ongoing work and eventual impact of the remediation project for community members using complex 2D maps, drawings and schematics, so we were excited to hear about BGC's Ada Platform," said Chris MacInnis, engineering manager, CIRNAC. "With Ada, community members were able to 'see' the remediation work happening 600 metres below ground in a simple, lifelike 3D environment and easily understand how the arsenic trioxide is being contained." See **Figures 2 and 3**.

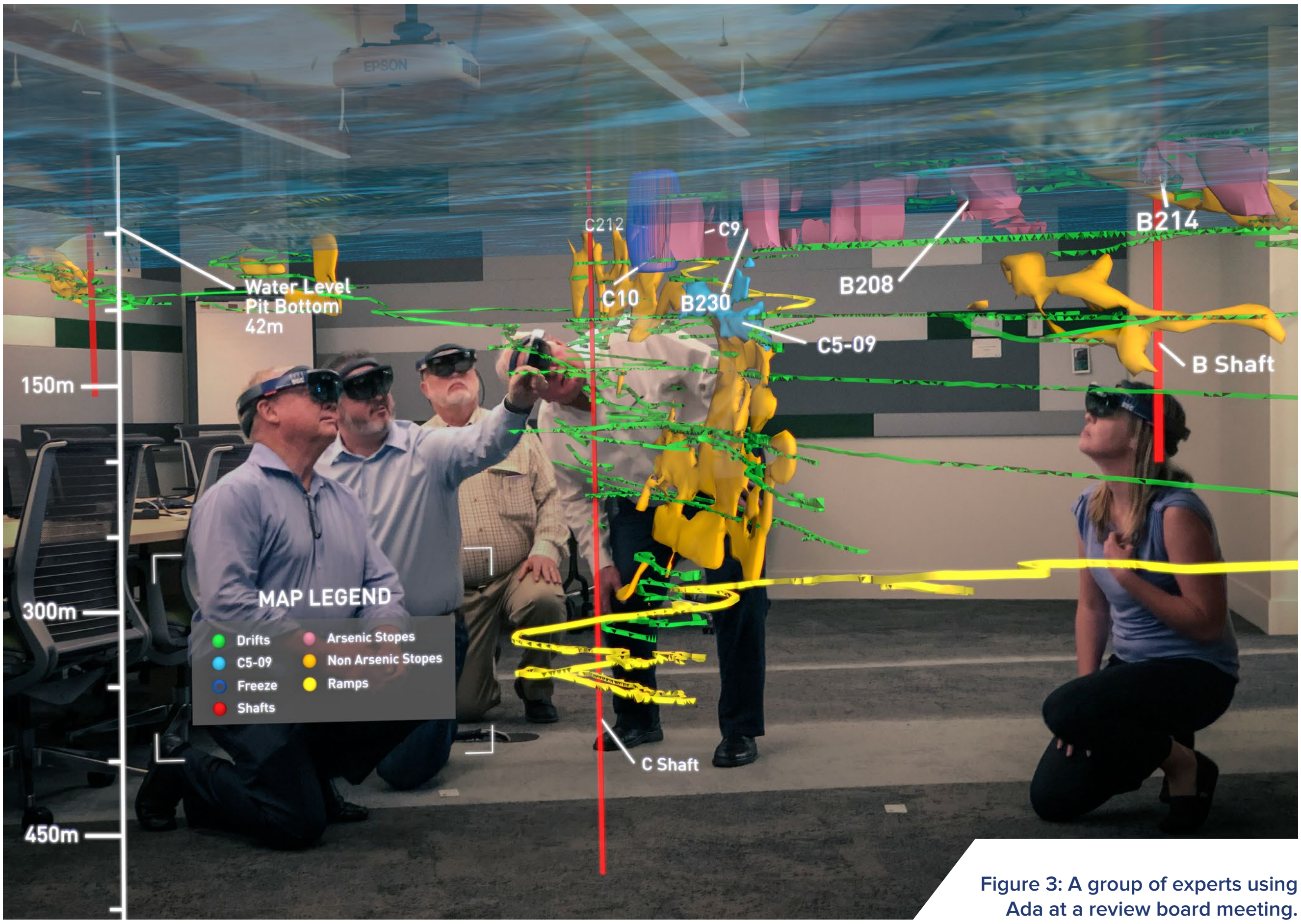


Figure 3: A group of experts using Ada at a review board meeting.

Holographic visualization allows people to interact with and control their experience, which facilitates the generation of a deeper understanding of 3D data and environments and their changes over time. This is especially important for the comprehension of non-technical project participants. Holographic visualization is enabling clearer communication and more confident decision making. It will also help identify, anticipate, and mitigate challenges earlier within the project lifecycle by being able to visualize the site in 3D on a boardroom table or standing in the landscape. It creates a shared vision, a common reality that allows meaningful input and decisions to be made based on science, facts and evidence.

"It's amazing to see how BGC's innovative Ada Platform has leveraged Microsoft HoloLens technology to bring complex infrastructure projects to life in a way that simplifies, captures attention and creates better understanding," said Mark Speaker, industry solutions executive, Microsoft Canada. "At Microsoft, we believe that mixed reality has the potential to transform the way people communicate, collaborate and explore. Like BGC, we're excited about the opportunities that mixed reality brings to the future of mining."

Mixed reality is a revolutionary step toward fully exploiting the potential of multidimensional data in a 3D environment.

Matt Lato is a senior engineer at BGC Engineering, based in Ottawa, Ontario, Canada. His technical expertise is in the application of three-dimensional remote sensing in geotechnical engineering. Matt is author or co-author of over 100 journal and conference papers. He is an adjunct professor in the Department of Geological Sciences and Geological Engineering at Queen's University, and an affiliate faculty member in the Department of Geology and Geological Engineering at the Colorado School of Mines. He holds BSc and PhD degrees from Queen's University.

Best Practices for UAS Operations

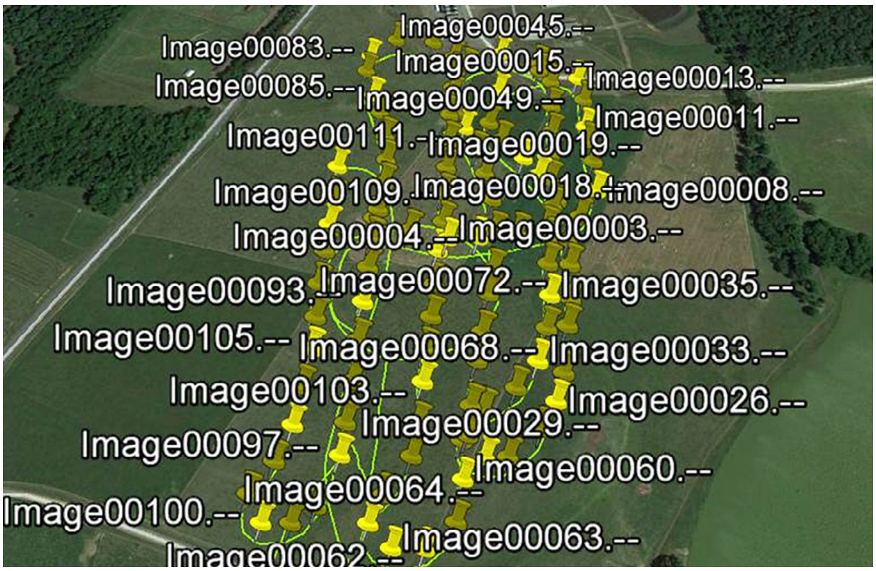


Figure 1: The exposure points after the data has been collected.

Earlier, a two-part paper was published on the "Evolution of the Point Cloud", in which data from different UAS platforms was evaluated. Six different UAS data collections were performed with camera and LiDAR sensor at two different altitudes. During the course of collection, the authors learned valuable lessons on UAS-based data collection and processing. In this paper we will discuss the "lessons learned" from this UAS project that has helped us in developing "Best Practices for UAS Operations"

The unmanned aerial systems (UAS) provide a new alternative approach to traditional aerial acquisition or ground-based surveys. Picking up where traditional methods of acquisition are limited either in ability or expense, UAS promise to unlock new opportunities for users of geospatial information. With UAS, one can create typical photogrammetric products at resolutions that are not available from conventional systems, and hybrid datasets from pixel-based point clouds, with per-square-meter densities not achievable from LiDAR, will drive the demand for new products.

Any UAS project will involve lot of planning and involves:

- FAA Regulations and insurance requirements
- Project Planning
- Flight Planning
- Flight Operations (Pre and Post)
- Ground Control
- Image processing

The FAA rules governing sUAS (small Unmanned Aircraft Systems) operations are published under 14 CFR 107, otherwise known as "Part 107." Part 107 includes requirements for all remotely piloted aircraft under 55lbs that are operated for any purpose other than recreational flying. Survey or other commercial operations are subject to the following requirements: faa.gov/uas/media/faa-uas-part107-flyer.pdf

The highlights of the requirements are that the pilot of the sUAS must hold a Remote Pilot Certificate issued by the FAA. The aircraft must NOT be flown

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


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

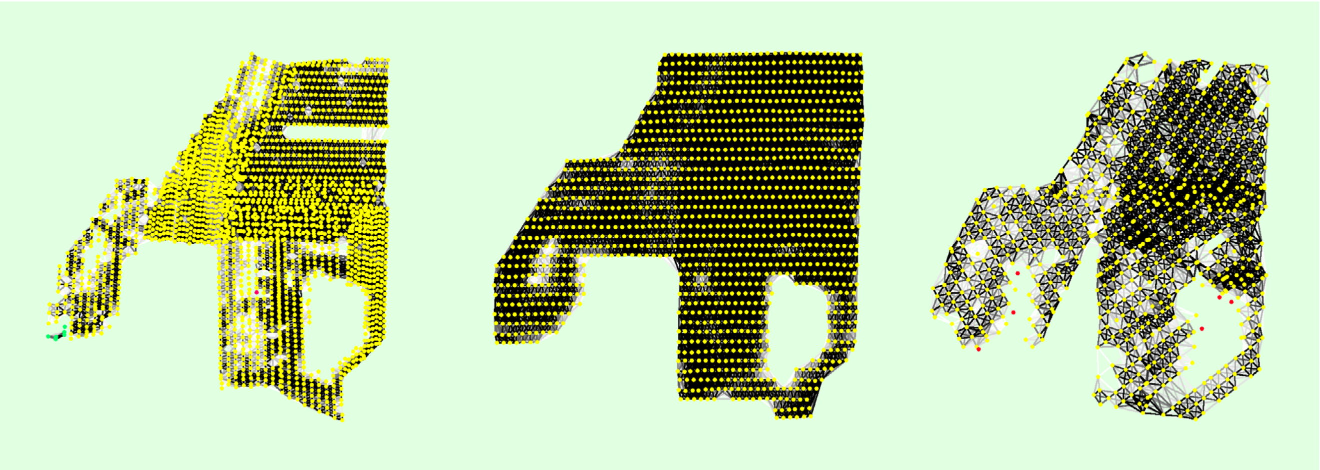


Figure 2: The cascading effect of missing flight lines with low overlap and poor quality of the blurry images has resulted in very few ties extracted.

beyond unaided visual line of sight, NOT be flown over 400ft above the ground, NOT be flown over people, and NOT flown in certain airspace. These rules can provide challenges for certain operations, and the FAA can issue certificates of waiver or authorization to bypass rules for special limited operations if risks are mitigated to acceptable levels. The RPIC (Remote Pilot In Command) is ultimately responsible for his/her flights.

It is important to remember that UAS aircraft must be operated under the FAA UAS guidelines. The issues that needs to be addressed at this stage are the

- Remote Pilot Certificate validity and any insurance coverage to the pilots
- Operational and safety requirements for all operational aircraft and at the project site
- State licensing laws that define the practice of professional engineering or surveying

Certificated remote pilots will understand aviation, air space regulations, navigational charts, aviation weather etc. The pilot may also need to go through the UAS manufacturer's training and have sufficient practice time on the aircraft of choice to ensure competent and safe operations. To conduct survey operations, the pilot also should have some exposure to aerial photogrammetry and LiDAR concepts.

It would be advisable to collect/collate all GIS layers that will play a role in the UAS data collection process

Project Planning

In project planning, decisions have to be made on the following:

- Type of aircraft
- Sensor (Camera/LiDAR)
- Terrain Conditions
- Project area
- Expected deliverables with accuracy requirements

Although, many different types of UAS may be capable of performing a project, we need to always remember the cost advantage of the UAS mission over a manned mission for the same project. In some cases, the manned mission may be more cost effective compared to UAS mission or may provide other important project priorities (e.g., safety or accuracy) that the UAS cannot provide.

Aircraft types include fixed-wing, VTOL, or hybrid. Time of flight for each platform (aircraft plus power source) are different and shorter flight times "per charge" will require more flights to accomplish the same task. These factors can make the costs to increase.

The selection of sensor depends on the deliverables and the terrain condition. For example, if the terrain is highly vegetated and the product deliverable is 1ft contour, then LiDAR sensor may be a better choice.

Terrain Conditions play an important role in the creation of product and has been explained in detail in the earlier paper.

Project area: The advantage of UAS is that data can be collected quickly for a small area (around 300 acres). But there are many instances where we may need data collection for larger areas. We need to make an estimate on how many hours/days it is going to take to collect the data given the aircraft. The time taken to complete data collection will have direct impact on the cost.

Expected deliverables with accuracy requirements needs to be kept in mind in project planning

Flight Planning

Like manned data capture, planning for a UAS based data collection is critical for the success of the project. Currently, many of the system manufacturers provide the flight planning software such as DJI GS pro, Pix4DCapture, DroneDeploy and Mission Planner.3rd party software is also often available for data capture.

The various parameters that need to be considered in UAS based data collection are

- Flight altitude
- Ground speed of the aircraft
- Forward and side overlap
- Ground Sample Distance (GSD)
- Shutter Speed
- frame capture rate

There is a common misconception that with a single-button press, a UAS pilot can operate the drone safely to capture all the images automatically. However, every project is unique. Many drones have 15-30 minute flight times, and it is necessary that flight plans for each lift required to cover an area are designed with sufficient forward and side overlap. Any underperformance in the overlap and side lap will lead to serious issues at the data processing stage and cause data voids in the point cloud.

Flight Operations (Pre and Post)

Best practices dictates that a checklist for the flight operation and the data capture teams are required and need to be reviewed carefully before each flight. The checklist will cover:

- Mission checklist
- Pre Flight Checklist
- Before Launch Checklist
- After landing Checklist

In any project, it is advisable, flight lines alternate directions and so contribute to a better estimation of frame centers when self-calibration is applied in the block adjustment. It is also advisable to ensure additional frames are collected at the end of each flight line. This helps ensure complete project coverage and high image quality results at the ends of flight lines.

> “The development of “best practices” encourages operational safety and the unprecedented benefits of UAS technology.”

As explained in our previous paper on “Evolution of the point cloud” published earlier, in order to take advantage of Structure from Motion (SfM) algorithms, the overlap should be 80% or above along the strips and 70% or above across the strips. This high overlap reduces image mismatches and increases the accuracy.

During the pre flight operations, care must be taken to insure the aircraft is properly calibrated. In order to avoid navigation and automatic stabilization problems, UAS often need an IMU and compass calibration on initial setup and when hardware changes are made. Operating very close to magnetically conductive structures or in magnetically disruptive environments may also cause challenges with the safe operation of UAS.

Post Flight: It is advisable that the pilot ensure that data is complete for the project area and that there are no missing data (e.g., frames, GPS) in the data collections. A variety of software are available to verify the data. These checks need to be completed before the pilot leaves the site to avoid refights at additional time and cost. Basically, the pilot should use the project boundary file, flight line file and the exposure points to ensure he has the complete coverage and that there are no gaps between the lifts. **Figure 1** shows the exposure points after the data has been collected.

Ground Control

Like any mapping project, ground control plays an important role in defining the accuracy of the derived product. Best practice dictates that some check points are collected along with control points. The check points are not used to adjust the project, but are used as an independent accuracy check. The important components of check points and control points are:

- Size and shape of the targets
- The number and distribution of check and ground control points

The control points must be easily identifiable. With proper overlap between images, it is guaranteed that

	High Altitude—VTOL	Low Altitude—VTOL	Low Altitude (Fixed wing)
Flight speed average (ft/sec)	31.5	34	50
Shutter Speed average	1/400s	1/240s	1/4000s
GSD (cm)	2.54	1.35	1.3
Blur (cm)	2.4 (1 pixel)	4.8 (4 pixels)	0.3 (0.3 pixels)
Matching Strength (Median matches/Median Keypoint)	17%	15%	51%

Table 1

the same control will lie in multiple images. Selecting these points in multiple images will increase the accuracy of the control point selection during processing. Placing distinct identifiers at each control point may also reduce errors in downstream processing.

Based on our experience, we suggest that the image size of the control points is 6 to 10 pixels. With the current GNSS surveys using RTK mode, horizontal accuracies of 1 -2 cm and vertical accuracies of 3 cm can be achieved. ASPRS standards require the surveyed accuracy of the control and check points should be at least 3 times better than the required project accuracies. For example, if the vertical accuracy of the final product needs to be 9 cm, then the control accuracy should be better than 3 cm.

Image processing

Time spent preparing a solid flight plan with a quality control layout greatly facilitates the most expensive part of an UAS project: the data processing. However, any deficiencies in the flight planning and data collection "roll down hill", that is, they impact data processing efficiencies, costs, and positional accuracy. The data collection should result with a minimum of 5 overlapping photos at any given point. More photos is always better. Less than 5 overlapping photos leads to difficulty in the aerotriangulation process.

Another important point that will play a role in the data processing is the shutter speed. It has been observed that the mismanaged exposure settings caused an average blur >0.5 pixel.

An analysis of the shutter speeds in the current project has resulted in the **Table 1**. As can be seen from the table, low altitude fixed wing data collection has resulted in smaller blur compared to VTOL. Although slower VTOL aircraft typically have fewer blur problems when flown slower, mismanaged exposure and shutter speed settings can cause problems. This table also explains the reason for getting below-par results with Inspire data collection.

Figure 2 shows the cascading effect of missing flight lines with low overlap and poor quality of the blurry images has resulted in very few ties extracted.

Conclusion

"Flying drones is easy. Mapping is hard." Accurately assigning ground coordinates to billions of pixels taken from an inherently unstable platform flying overhead is really hard. Professionals understand this and have established "best practices" to ensure the quality and accuracy of the final mapping deliverables reliably and predictably meet the project specifications. Shortcuts are tempting but are often quite costly. As our profession communicates these important principles, the drone practitioners, the public and our clients benefit with world-class geospatial information.

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creating a rich, fused data product but simply an analytic result. To carry out this analysis I might find the centroids of the building footprints as compact X, Y points (I probably do not need the elevations). I could then transport these to the region containing the lidar data. I would then find the difference between the union and intersection of the centroids and the lidar building classes. The result would be a compact set of centroids that represent the change.

The difference between these two processing models can be subtle until you get your cloud services bill! There is an old adage regarding large dataset processing: "move the processor to the data." This could be quite difficult in complex on-premise physical environments but is generally quite easy in virtualized cloud environments. When playing the game to reduce cost, it can often be useful to extract just the bits you need from each data source and then do the fusion. In the case of colorizing lidar data, we are pretty much stuck. The parts of the data we need to bring together represent the bulk of the size, so just grit your teeth and move the lighter to the heavier (in this example, the image data are "lighter"). Of course, you can play some tricks such as doing any necessary subsampling prior to data transmission. It goes without saying that you always employ a very efficient data compression scheme prior to transmission. And whatever you do, avoid truly bloated data schemas such as KML, XML and GeoJSON when dealing with voluminous data (I guess we have proven that there are, indeed, formats less efficient than ASCII—anyone care to join us in porting Shape to 64 bit?).

As developers, we have always been aware of the cost of processing in terms of storage devices, processing time, user experience and so forth. Actually paying rapidly multiplying pennies for computer and transfer resources brings this to the forefront of design. The bottom line here is that you have a new consideration when designing for metered, virtual environments.

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The issue with lidar has been cost, which is falling, but would still run to thousands of dollars for outfitting a mass-market vehicle. Lidar makers say the price will come down as manufacturing scales up, but automotive lidar will never be headlight-cheap. This would be a problem if everybody was buying their own self-driving car. But autonomous vehicles will mostly end up in fleets zipping around doing picks and drops at all hours. For many, owning a car to commute will make as much sense as owning a cell tower to scroll Instagram. We'll just subscribe and let the automotive equivalent of Sprint or Verizon deal with the infrastructure. If this seems far-fetched, consider that Uber has spent more than a billion dollars on autonomous vehicle research because it envisions itself as an automated, driverless service. It's all but certain that, in the not-so-distant future, the human Uber driver will seem as archaic as a Netflix DVD in a Tyvek mailer.

Musk is right, therefore, that lidar is a crutch. But so are Google (brain crutch), contact lenses (eye crutch) and, indeed, crutches (crutch-crutch). Crutches are assistive, enabling technologies. Perhaps one day cameras and radar alone will be enough for safe self-driving. But lidar has been a fundamental enabler of the rapid advance of autonomous vehicle technology, and it will make self-driving cars and trucks safer than they'd otherwise be. It's the sort of crutch I'll want to lean on when my daughters—and, maybe one day, my grandchildren—ride off in a car with no driver.

Todd Neff is the author of *The Laser That's Changing the World*[1], a history of lidar.

[1] Neff, T., 2018. *The Laser That's Changing the World: The Amazing Stories behind Lidar from 3D Mapping to Self-Driving Cars,* Prometheus Books, Amherst, New York, 314 pp.

LEWIS GRAHAM

Analyze This!

Our company, GeoCue Group, has been doing a lot of work these past two years in the areas of data processing and management running in Amazon Web Services (AWS). There is a game you play with AWS (and other "cloud" vendors) to try to reduce the cost of using the service. It is an interesting fact that cloud architectures represent a compromise between designs optimized for the host architecture/use cases (the science bit) and the goal of minimizing system rental costs (the business bit).

At any rate, this analysis of our deployments in AWS made me start thinking about the term "data fusion." We toss this round a lot; in fact, I think one of my previous Random Points random ramblings was on this very subject. Recently, I have come to appreciate a subtle distinction between data fusion and what I will call "analytic fusion". This distinction matters a lot when you are paying a cost (dollars or time) for moving data.

Traditional data fusion means mixing data from different sources (e.g. sensors) to create a product that is either better than the individual sources alone or is aimed at a special application. The primary goal is to create a new data set that is richer in content than any of the individual source data sets. An example is shown in **Figure 1**. This is a point cloud from United States Department of Agriculture (USDA) lidar data colorized with image data from the USDA National Agriculture Imagery Program (NAIP). This fused data product was generated in GeoCue's Earth Sensor Portal, a data management and cataloging system hosted in AWS. This product is creating by populating red-green-blue (and, optionally, near-infrared) data fields in the lidar data (in LAS format) with the interpolated image data from the NAIP. The result is a beautiful, colorized 3D point cloud that is useful in myriad applications. This is the key thought, however when creating a *data fusion* product, we are not completely sure what will be asked of the result.

Figure 1: Fused USDA lidar, NAIP imagery

Generation of this product requires moving data from the storage location of the NAIP to the storage location of the lidar data. Some NAIP is stored in AWS East Region, whereas most USGS lidar data are stored in AWS West Region. It can cost up to 9 cents per gigabyte to move data between AWS regions, so this is a major consideration when designing a cloud-hosted environment to perform the fusion process.

Analytic fusion, on the other hand, is aimed at using two or more sources of data to answer a specific question. The goal is not to mash the data together to generate a new, richer data set, but rather just to seek solutions to some specific problems that are known *a priori.* An example might be to use a feature layer containing building footprints and a set of lidar data with classified building points to look for areas of change. Here I am not interested in

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