VOLUME 7 ISSUE 8

LIDAR MAGAZINE

DECEMBER 2017

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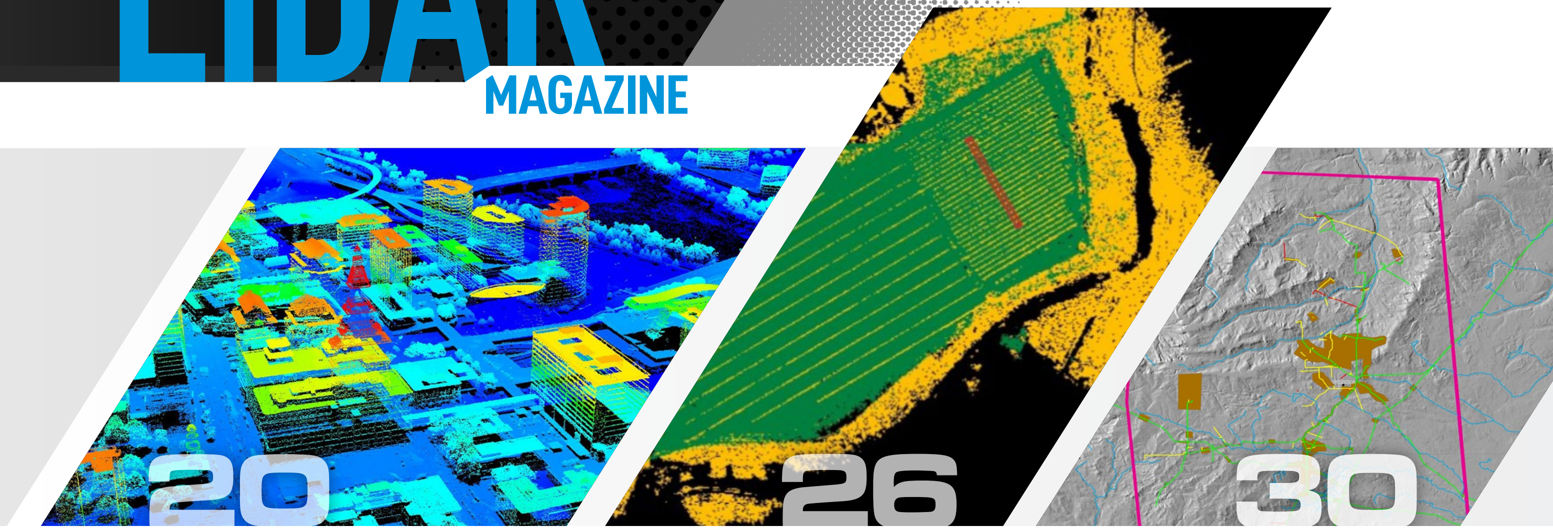

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TerraSAR-X Satellite Image
Deister, Germany. Image Type: Radar

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Complementary Technologies

Still coming to grips with my new role, I am fortunate to have attended two excellent conferences. The Commercial UAV Expo in Las Vegas, Nevada, in late October was vibrant and well run by Diversified Communications, attracting around 2000 attendees from 53 countries and 150 exhibitors. The excitement of walking the aisles amidst booths bedecked with UAVs of all shapes and sizes doesn't abate. One of the key happenings, however, was an announcement by Lisa Murray, Director of Commercial UAV Expo, during her opening remarks, that Diversified Communications had acquired Drone World Expo from JD Events. Drone World Expo has historically taken place in San José, California, but from next year the two events will be combined and will take place on 1–3 October 2018 in Las Vegas. As LIDAR sensors become smaller and lighter and more companies master their integration on to UAVs, the LIDAR community can be expected to flock to Nevada. ASPRS ran several sessions at this year's event, including one in which candidates for the Society's recently launched UAS certifications (Certified Mapping Scientist, UAS; Certified UAS technologist) took their examinations. The result was an unprecedented 14 successful candidates in one day! ASPRS plans to expand on this by offering examinations for its LIDAR certifications (Certified Mapping Scientist, LIDAR; Certified LIDAR technologist) during ILMF, which takes place in Denver on 5–7 February 2018. This is the first time ASPRS will hold its annual conference in conjunction with ILMF, resulting in an unprecedented number of exhibits, combined networking opportunities, and the innovative GEO League Challenge, which will pair students with industry professionals and academics to compete in a fun event open to all attendees.

Whereas it sometimes seems that any geospatial event these days is dominated by UAVs, this was certainly not the case at the 20th William T. Pecora Memorial Remote Sensing Symposium (Pecora 20 for short), run jointly by ASPRS, USGS and NASA in Sioux Falls, South Dakota in mid-November. It attracted about 450 participants. The Pecora Symposium series was established by the USGS and NASA in the 1970s as a forum to foster the exchange of scientific information and results derived from applications of Earth observing data to a broad range of land-based resources, and discuss ideas, policies, and strategies concerning land remote sensing. It commemorates William Thomas Pecora (1913–72), who

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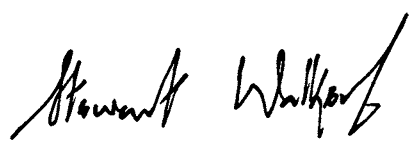
advocated, when he was director of USGS in the 1960s, for the creation of a remote sensing satellite that would be used to gather information about the surface of the Earth, which resulted in the launch of ERTS 1, now known as Landsat, on 23 July 1972. Currently Landsats 7 and 8 are flying and we learned about the progress of Landsat 9, due for launch in December 2020, and further missions beyond that. We are blessed with more than 40 years of imagery, providing rich time series to help us learn what has happened to our planet. Does Landsat imagery have anything to do with LIDAR? Many presenters were involved in calibration, experts in the science underlying the processing of Landsat imagery to be consistent and most likely to give trustworthy results. One made an intriguing remark to me. He felt that the demand for calibration of high-end airborne cameras, flown in manned aircraft, is lessening, perhaps owing to the remarkable performance of medium-format cameras, or perhaps to the effect of the use of UAS imagery, which is displacing conventional manned photogrammetric missions for certain applications. If he is correct, could a similar trend eventually emerge for LIDAR? Moreover, I attended a session in which multiple presenters talked about using Landsat and LIDAR together to estimate various quantities, such as tree height and biomass, required for forest management. This is a bellwether, since the combination of complementary technologies is crucial to the geospatial future—we'll regularly address the topic of data fusion, moving forward.

Last month I promised to follow up on "certification, licensure, ethics, standards, guidelines and procurement regulations". ASPRS maintains a leadership role in the development of guidelines, standards, specifications, and calibration processes for those sensors and activities of primary importance to the membership by using established procedures for developing, reviewing, modifying, approving standards, and publishing them. A USGS-ASPRS Work Group (WG) has investigated various factors associated with the geometric quality of LIDAR data. The WG has noted that while the quality of LIDAR data has improved tremendously in the past few years, the QA/QC of these data is not standardized, including the semantics, processes for measurement and reporting, and meta data. To ensure the geometric quality of LIDAR data, the WG has recommended several topics for research and development. In addition, the WG created guidelines on quantifying the relative horizontal and vertical errors observed between conjugate features in the overlapping regions of LIDAR data. The effort has been supported by the USGS National Geospatial Program (NGP) and the Land Remote Sensing (LRS) program. In March 2017, ASPRS implemented the first phase of an outreach campaign by approving draft versions of *Summary of Research and Development Efforts Necessary for Assuring Geometric Quality of LIDAR Data* and *Guidelines on Geometric Inter-Swath Accuracy and Quality of LIDAR Data* and releasing them for review by the membership. Industry stakeholders and the general public were invited to participate in the approval process by downloading the draft versions, reviewing the content, and providing comments with a final deadline of October 30, 2017. These inputs are under review by the WG and the documents being revised as appropriate. When the final versions are published, we will have an article about them in *LIDAR Magazine*.

No-one complained about me using space in last month's editorial to describe two interesting items I had found as I scan my collection of thousands of technical papers and brochures. Less treasure has been uncovered this month, so my eye was drawn by something current instead. LIDAR is not typically associated with the "dismal science", yet earned a paragraph in *The Economist* of 4 November 2017, in an article about the Lockheed Martin Matrix, a full-size unicopter development, sponsored by DARPA, that is expected to fly early in 2018. "The main sensor is a form of LIDAR, the laser equivalent of radar. LIDAR is a part of the equipment of driverless cars, but the Matrix version is more powerful. It can detect objects hundreds of meters away."[1] Our technology is on coffee tables, tablets and phones the world over!

In closing, I wish all of you a successful and healthy 2018!



A. Stewart Walker // Managing Editor

[1] Anon, 2017. Back to the unicopter, *The Economist*, v425, #9065, p78.

The Bare Earth

How LIDAR in Washington state exposes geology and natural hazards

Courtesy of the Washington Geological Survey, a Division of the Washington State Department of Natural Resources (dnr.wa.gov/geology)

For geologists, LIDAR is an invaluable tool that enables them to see and study large areas of the earth's surface, particularly in places where trees and vegetation obscure the landscape. To celebrate GIS Day, the Washington Geological Survey released a new story map titled "The Bare Earth", an incredible walk-through of how LIDAR is used to expose geology and natural hazards.

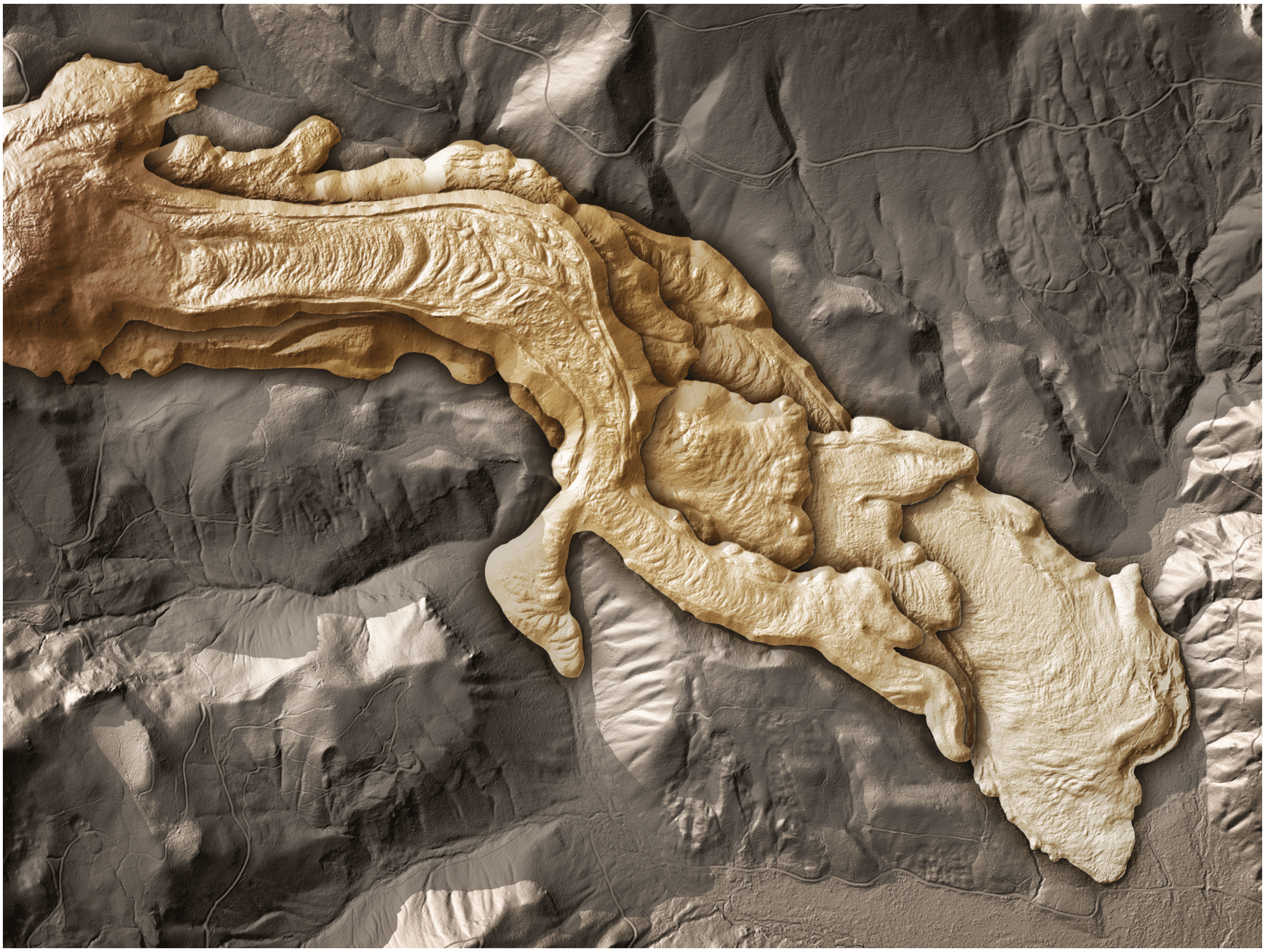
LIDAR bare-earth models allow closer study of geomorphology. Landslides, faults, floods, glaciers, and erosion leave their mark on the landscape, and while these marks can be hidden by dense vegetation, they can't hide from LIDAR.

Special thanks to the Washington Geological Survey for this engaging and immersive tool!

Landslides

Before the use of LIDAR became widespread, geologists used aerial photographs, topographic maps, and field surveys to catalog landslides. This method is problematic in much of Washington State because of the density of vegetation that often obscures features and makes field checking difficult.

In this bare-earth LIDAR image, multiple landslides are visible along the Cedar River in King County.



In this LIDAR bare-earth image, the multiple lava flows of West Crater in Gifford Pinchot National Forest are separated into distinct layers.

Volcanoes

Washington State has five major active volcanoes—Mount Baker, Glacier Peak, Mount Rainier, Mount Adams and Mount St. Helens. Each has erupted in the past 250 years except for Mount Adams. Repeated LIDAR surveys over time can be used to monitor volcanic activity.

To view the story map with image comparisons and other information, visit: arcg.is/2BB4jKq

POINTS & PIXELS

In this composite LIDAR/photo image, the Toe Jam Hill fault scarp (a strand of the Seattle fault zone) is clearly visible in the landscape on Bainbridge Island in Kitsap County.

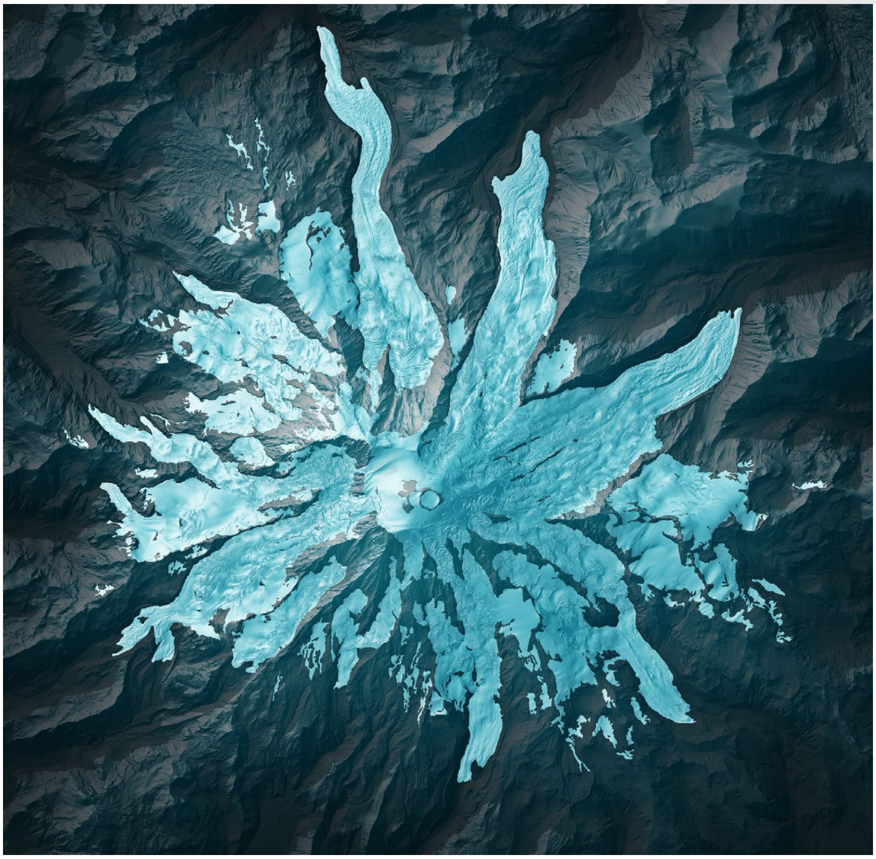
Faults

Washington has dozens of active faults and fault zones. Some of these faults are in remote areas. Others, like the Seattle Fault and southern Whidbey Island fault zone, underlie major cities and pose a significant hazard. Signs of young faults include sag ponds, offset stream beds, and linear scarps. LIDAR gives geologists the ability to find these features no matter what the ground cover is like or if the feature is partly eroded.

Tsunamis

Tsunamis are a potential threat in coastal regions of Washington. LIDAR gives scientists an accurate surface representation of the ground, and in combination with bathymetry data, allow models to more accurately predict where a tsunami could inundate an area. This modeling can give residents the ability to plan where to evacuate during an emergency.

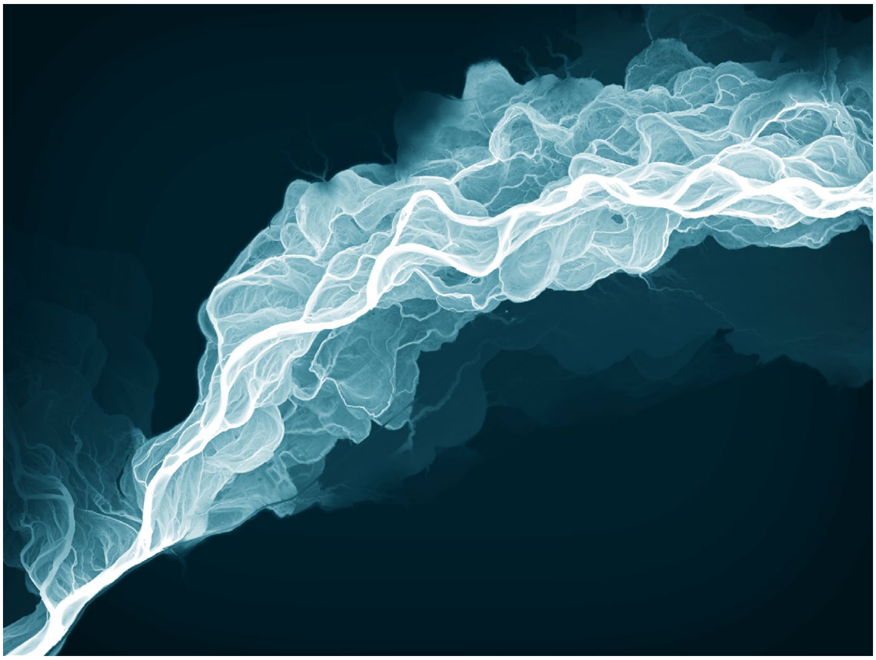
In this bare-earth LIDAR image, the contrast between the uplands and lowlands of Cape Disappointment is clearly visible.



This LIDAR shaded-relief image delineates and emphasizes the glaciers and snowfields of Mount Rainier National Park.

Glaciers

Washington has several large glaciated peaks and mountain ranges. LIDAR can be used to monitor the growth or decline of the glaciers in these locations. Repeated monitoring over the same area documents the effects of climate change or geologic activity. Additionally, geologists can use LIDAR to discern the glacial history from the last ice age by identifying features such as moraines and outwash channels.



In this LIDAR relative elevation model (REM) the current and former channels of the Sauk River in Skagit and Snohomish Counties are emphasized.

Rivers

LIDAR is useful for many hydrologic applications in Washington. Floodplains can be mapped in detail to show where areas are at risk to flooding. Subtle river features, such as abandoned channels, ditches, terraces, and levees can be identified. This allows land managers and decision-makers to manage flood zones, preserve the natural functions of floodplains, and better craft emergency response procedures.

New AEC Industry Report Features 18 Tips for Achieving Fast, Accurate Structural Steel As-Built Models

The new report from ClearEdge3D offers 18 structural steel as-built pro tips and two case studies for taking maximum advantage of today's automated field capture and back-office "as-built" modeling tools.

Manassas, VA — ClearEdge3D has released a new report that highlights 18 tips for optimizing project efficiency and as-built model accuracy. Scanning and modeling professionals from Allen Construction Services, Cadworks, and Hale TiP share their experiences and insights utilizing 3D laser scanning and automated modeling software tools. Two case studies examine how these tools allowed the firms to meet ultra-demanding deadlines with incredible data and model precision.

The 18 tips are organized into three categories: project management, field data capture, and project modeling/deliverables. Tips from these AEC industry professionals include:

Project Management Best Practices

Establish a data management plan that defines requirements around data processing, storage, and access. "In the beginning, we were using Dropbox to place the data," said Jake Allen, CEO of Allen Construction Services. "Someone who was not involved with the project had access to Dropbox and deleted project data files. It was a valuable lesson learned."

Field Data Capture Effeciencies

Use multiple scanners for maximum efficiency. "We achieved 2.5X field efficiency by using two scanners and 2 field staff," said Greg Hale, CTO, Hale TiP. "It's noticeably better than simply 2X because staff can help each other use a leap frog approach for scanning and help with QC, etc." Using drones and scan targets are also mentioned for field data capture optimization.

Office Modeling & Deliverable Creation Tips

Implement a workflow that combines ClearEdge3D EdgeWise™ software and Autodesk® Revit® to improve accuracy of the final model based on the software's precise modeling algorithms and robust QA/QC tools for piping and structure. "Extraction software is more accurate than humans because we approximate too much," says Hale. "Modeling existing conditions can be very challenging. EdgeWise doubles our modeling speed and, at the same time, allows us to mitigate risks by providing accurate representations." Using ClearEdge3D Verity™ software as a model checker is also considered a back-office best practice.

"3D laser scanning has rapidly gained popularity for its automatic capture of complete as-is geometry of structures and sites," said Chris Scotton, CEO of ClearEdge3D. "Users like the ones interviewed in this report have also increasingly turned to automated software tools like EdgeWise and Verity that help them quickly convert rich laser scan point clouds into accurate as-built CAD and BIM deliverables."

This free report is available for download at http://info.clearedge3d.com/steel-report-pr

ClearEdge3D is a global technology leader in the Architectural/Engineering/Construction (AEC) industry, offering advanced software solutions that help firms model existing conditions and verify that recently completed work has been constructed correctly. The company's EdgeWise software dramatically speeds labor-intensive 3D modeling workflows by utilizing advanced automated feature extraction and assistive modeling technology. Its Verity construction verification software compares point cloud data of recently completed work against a design or fabrication model, flagging any out-of-tolerance or poorly installed elements. For more information, please visit www.clearedge3d.com.

CHANGING OF THE GUARD

ADDRESSING COMPLEMENTARY TECHNOLOGIES

UWE SÖRGEL

Following his accession to the chair of the Institute for Photogrammetry (ifp) at the University of Stuttgart, Professor Uwe Sörgel chaired the 56th Photogrammetric Week in September 2017. Stewart Walker, new managing editor of *LIDAR Magazine*, interviews him to explore the evolution of this world-renowned center of photogrammetric excellence and the conference associated with it, and solicit his thoughts and ideas about the technologies that are shaping our LIDAR world.

In early September every odd-numbered year, photogrammetrists from around the world gather in Stuttgart, the capital of the province of Baden-Württemberg in southern Germany, for the Photogrammetric Week. This year the event was presided over by Professor Uwe Sörgel, who replaced Professor Dieter Fritsch as chair of ifp in April 2016. Professor Fritsch, in turn, had, in 1992, succeeded Professor Fritz Ackermann, who had occupied the chair since 1966. The chair is not only prestigious and one of the most sought after academic positions in photogrammetry, but its occupant doesn't change often. The arrival of Uwe Sörgel, therefore, is a significant event and *LIDAR Magazine* took the opportunity to learn more about him and his ideas.

INTERVIEW BY DR. A. STEWART **WALKER**

Universität Stuttgart

UNIVERSITY OF STUTTGART

Founded in 1829, the University of Stuttgart has a student body of 28,000. It has campuses in downtown Stuttgart and Stuttgart-Vaihingen. Its strengths include engineering and computer science and it now offers masters courses in the English language. The **University of Stuttgart** is one of the leading technically oriented universities in Germany with global significance. It sees itself as a center of university-based, non-university, and industrial **research**. Furthermore, it takes a role as a guarantor of research-based **teaching**, focused on quality and holism.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LIDAR Magazine: Professor Sörgel, thank you for talking to us. Could you please tell us a little about yourself and your background?

Uwe Sörgel: In 1997, I received the degree Diplomingenieur (equivalent to MS) in electrical engineering from the University of Erlangen-Nuremberg, Germany. During my studies, I focused on digital processing of audio, image and video signals. From 1997 to 2005, I was research associate at the Institute for Optronics and Pattern Recognition (FOM), located in Ettlingen (Germany), which was part of the Research Institute for Applied Natural Sciences (FGAN), a former German research establishment focusing on defense-related studies, now integrated into the Fraunhofer. At that time, I was mainly involved with pattern recognition of man-made objects from remote sensing imagery, with emphasis on synthetic aperture radar (SAR) data. In 2003 I received my PhD in electrical engineering and computer science from Leibniz Universität Hannover, Germany. From 2006 I worked as assistant professor then associate professor for radar remote sensing and active systems at Leibniz Universität Hannover. In 2013 I was appointed full professor for remote sensing and image analysis at Technische Universität Darmstadt, Germany. Since April 2016 I have been full professor at the University of Stuttgart and Director of the Institute for Photogrammetry.

LM: What prompted you to seek the chair in Stuttgart?

Sörgel: I was looking for a new challenge and the appointment at the Institute for Photogrammetry at Stuttgart University promised prospects of conducting larger research projects and organizing workshops to serve the scientific community. Moreover, since the very beginning ifp has enjoyed a high worldwide reputation in the field of photogrammetry and this itself has opened many opportunities for networking and project acquisition.

LM: When you arrived, what did you to consider to be the strengths of ifp and what did you wish to change? Have you been able to make the changes you would like?

Sörgel: Due to its long history—more than 50 years—ifp has had two main areas of expertise. The founder, Prof. Fritz Ackermann, is widely considered as the most influential scientist of his generation in the field of photogrammetry, and his successor, Prof. Dieter Fritsch, added geoinformatics as a second research pillar. I am in the happy position that highly-skilled permanent staff are available in both research fields. Therefore, I would be well advised to continue research in these two very successful fields, photogrammetry and geoinformatics. In addition, we have started to establish remote sensing as a third pillar of the ifp curriculum, emphasizing SAR, airborne laser scanning, and time series analysis. We will of course strive for close cooperation with other research groups, which is easily achieved: in all areas we more or less deal with information extraction

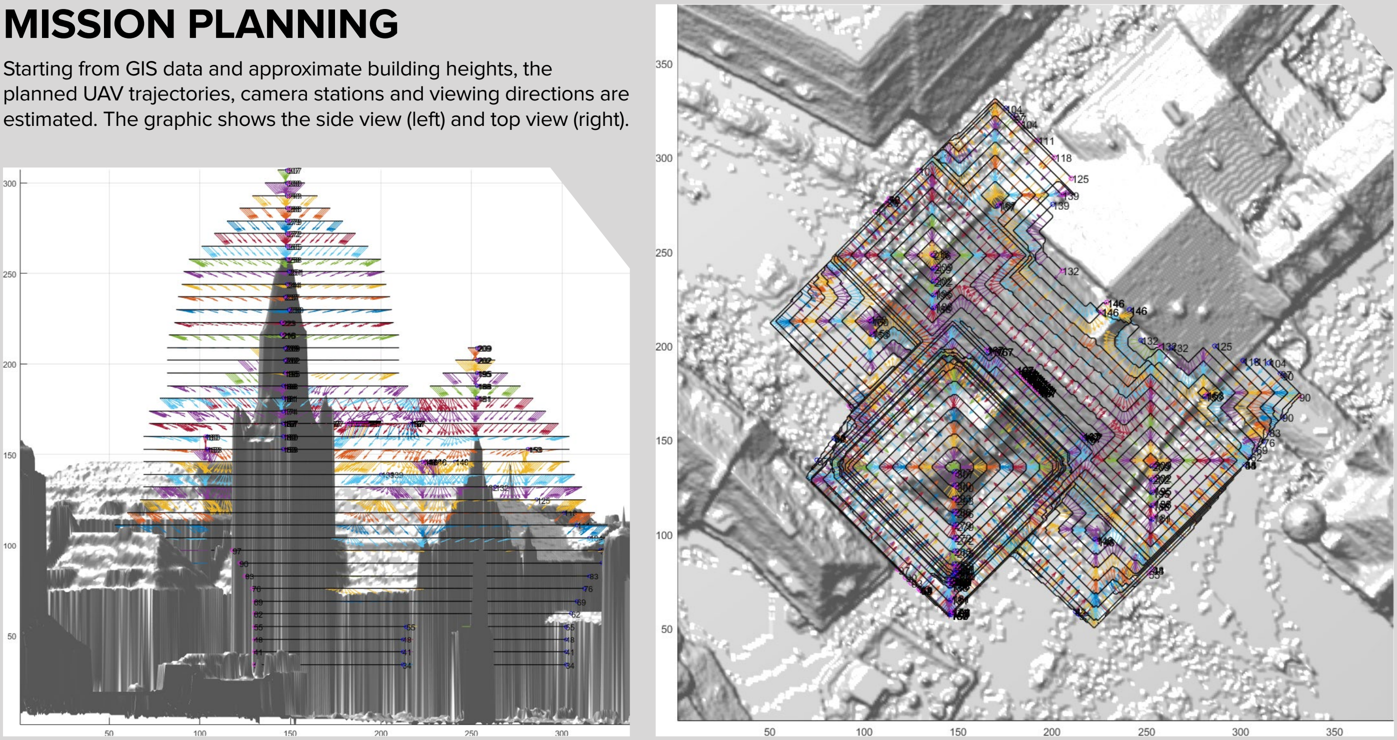
ifp

The Institute for Photogrammetry (ifp) was founded in April 1966, coinciding with the appointment of Fritz Ackermann to Professor for Photogrammetry and Surveying. Prof. Dieter Fritsch succeeded Prof. Ackermann in 1992 and also served as Rector of the University of Stuttgart from 2000 to 2006. The Institute offers undergraduate courses in photogrammetry, image and signal processing, remote sensing, and geoinformatics. It has about 15 masters and 10 doctoral students. The faculty includes Prof. Sörgel as chair, Prof. Norbert Haala as deputy (research area: photogrammetric computer vision), Dr. Michael Cramer (photogrammetric systems) and Dr. Volker Walter (geoinformatics). Prof Sörgel is also head of the remote sensing research group. There's a detailed account of the Institute's first 50 years at www.ifp.uni-stuttgart.de/institut/50Jahre/ifp-50Jahre-Festschrift-Web.pdf.

The Institute is very active in international research and current work includes several areas where developments are made of technologies complementary to LIDAR. One example is flight planning for UAVs over structures, to ensure that the camera positions are optimized for point cloud generation and reconstruction of buildings and façades. Another is the use of persistent scatterer interferometry (PSI) for 4D change detection in urban areas.

MISSION PLANNING

Starting from GIS data and approximate building heights, the planned UAV trajectories, camera stations and viewing directions are estimated. The graphic shows the side view (left) and top view (right).



from mass geodata, pattern recognition and image analyzing methods—a common base which we will further develop.

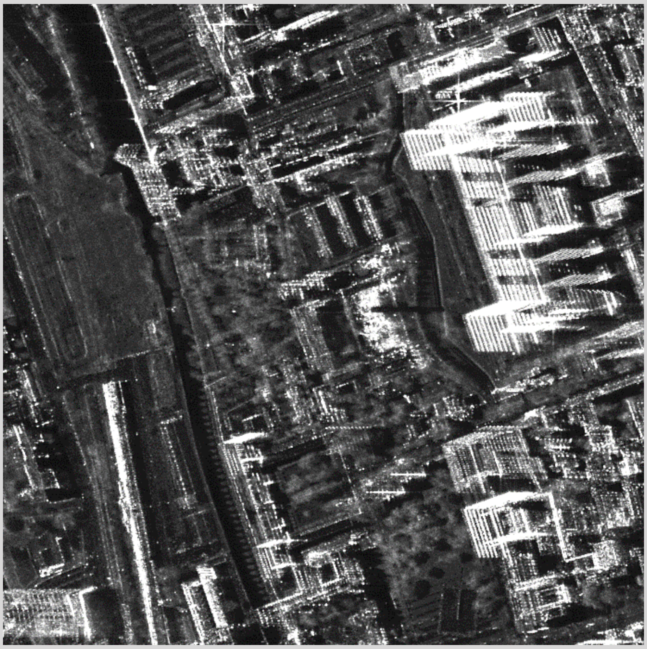
LM: The Photogrammetric Week is changing too. We noticed the obvious things—more synthetic aperture radar (SAR) and remote sensing in the optional tutorial on the Sunday; some sessions were chaired by your deputy, Professor Norbert Haala, rather than yourself; there was no traditional group photo on the steps between the two buildings where the conference is held; and no hardcopy book containing the papers. But there must have been other changes behind the scenes—how do you perceive the event evolving?

Sörgel: Well, also in the past the Photogrammetric Weeks (PhoWo) were not static events. My predecessors always focused on hot topics of the day. Core themes of the 2017 PhoWo were autonomous driving, precision farming, and BIM. The same applies to the tutorial, which covered remote sensing, in particular SAR interferometry, but also modern classification methods, which are useful for photogrammetry as well. The long-term basis of PhoWo is and will be the same as in the past: photogrammetry, remote sensing and geoinformatics, in terms of both research and applications. In my eyes, this combination of theory and practice is a unique selling point of PhoWo, a path we plan to continue in the future. In addition, an essential keystone of this event is and will be our OpenPhoWo partners, whose interesting demonstrations in the afternoons were well attended. Meanwhile we already have collected a lot of feedback from PhoWo attendees from academia, companies, and government as well as from our OpenPhoWo partners, which was in general quite encouraging. Hence, we will strive to follow the path of success so far: maintain the fundamentals but be open for innovation at the same time.

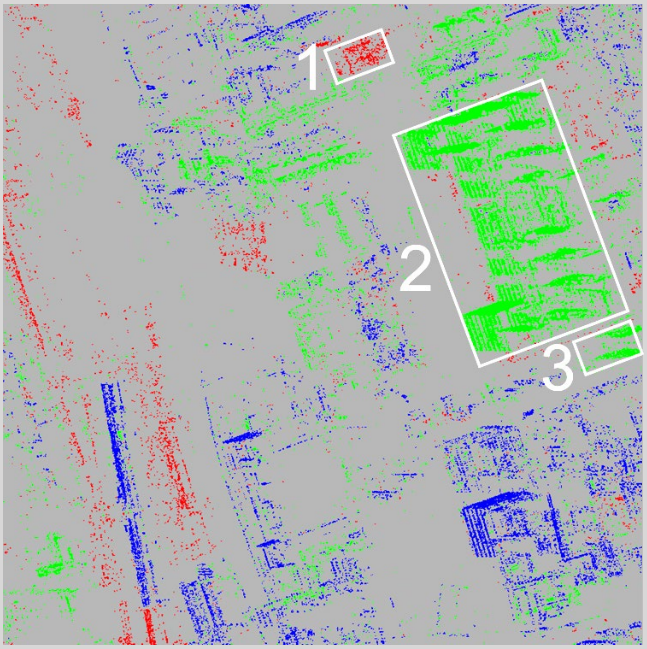
PhoWo is a joint activity of the whole institute. Prof. Norbert Haala and other senior staff members were involved in the selection of invited speakers for the scientific sessions taking place in the mornings. As Norbert is an outstanding expert in the field of photogrammetric image analysis, it was an obvious choice that he should chair the related sessions. Full papers of invited speeches are widely regarded as a kind of grey literature in the community. We therefore decided not

PERSISTENT SCATTERER INTERFEROMETRY (PSI)

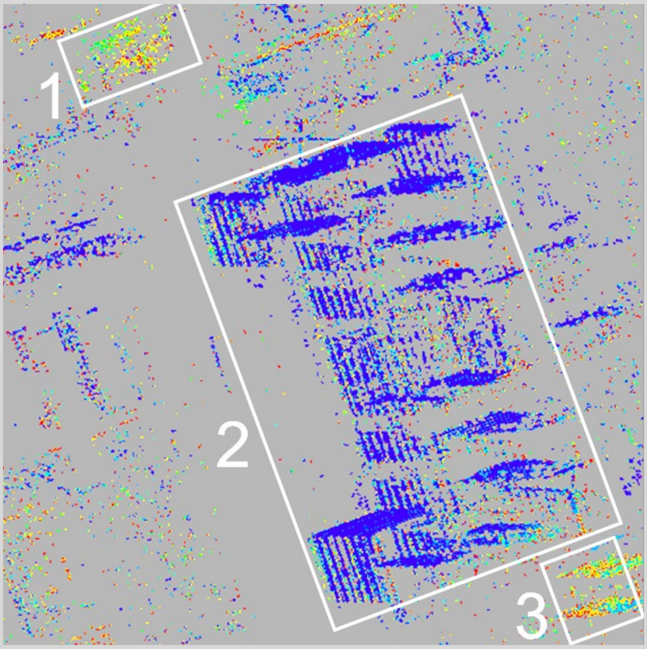
Google Earth image of a scene in center of Berlin, Germany (2014.09.05)



Average amplitude image of a stack of 40 TerraSAR-X acquisition collected in between 2010-14. Note the salient bright dots caused by strong scatterers (PS) preferably found at building facades and roofs.



Result of analysis: PS found at steady structures (blue), disappearing structures (e.g., buildings demolished during observation period like in the left part of the scene, red), and emerging structures (e.g., newly erected buildings, green)



Detail analysis: color code indicates event occurrence times within 2013. The salient large building block in rectangle 2 was erected in spring, whereas buildings in region 1 and 3 have been demolished and erected, respectively, later during fall.

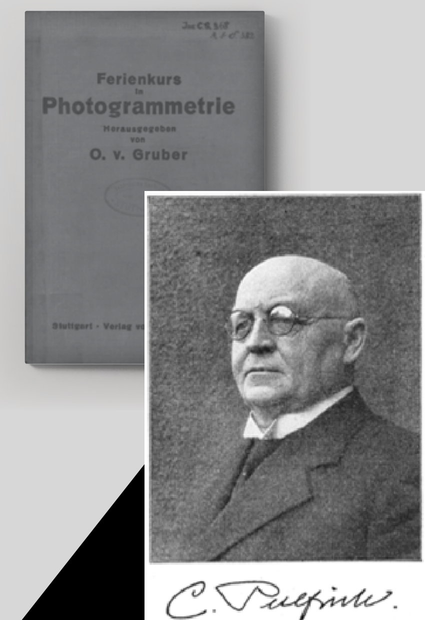
to continue with full papers printed in hard copy, instead we provided the attendees with digital versions of the extended abstracts. In addition, the authors provided pdf files of their slides, enabling the audience during the talks to write their own comments and thoughts into such files for a later use. This new opportunity was widely appreciated.

LM: You are an expert on SAR and related technologies such as interferometric SAR (InSAR) and polarimetric SAR (PolSAR). How would you describe the principal contributions of these technologies within the geospatial toolbox? How are they changing? Also, we have come to associate these technologies more with satellites than aircraft, especially the well-known constellations Radarsat, COSMO-SkyMed and TerraSAR-X/TanDEM-X. We have noticed that several smallsat constellations have been announced that will carry SAR sensors—do you think they will be successful and how will they change the utilization of SAR data?

Sörgel: In my opinion, SAR interferometry, including advanced variations such as differential interferometry (dInSAR) and persistent scatterer interferometry (PSI), are *the* hot topics of radar remote sensing, not to say remote sensing as a whole. Missions such as SRTM and TanDEM-X were tremendous success stories. One could argue, however, that comparable DEMs can be derived by other means, for instance, by stereo photogrammetry based on optical satellite imagery. Nevertheless, monitoring subtle surface deformation processes of various kinds for large areas is possible only by dInSAR and PSI based on time series of satellite SAR data. At the same time, we have had an enormous demand for such monitoring. On the one hand, we deal with surface motion due to natural processes or hazards such as volcanic activities, earthquakes, or landslides. On the other hand, we face issues caused by anthropogenic activities, which may in particular threaten urban areas. Most people's first association with the latter is subsidence during or in the aftermath of underground mining or construction. For example, in the Ruhr area of Germany we saw in some places subsidence of about 20 m since the mid 18th century. And many other places in the world share the same problem. But there is another issue, which is often overlooked in public: subsidence caused by overstrained ground water removal, a problem which occurs

MERGING TECHNOLOGY AND TRADITION

The Photogrammetric Week began as the "Vacation Course in Stereophotogrammetry" in 1909 (a detailed history has been written by Dieter Fritsch: http://www.ifp.uni-stuttgart.de/publications/phowo05/010fritsch.pdf). The course was the brainchild of Dr. Carl Pulfrich, a brilliant employee at Carl Zeiss Jena, to whom the concept of stereoscopic measurement is attributed. The event attracted 46 participants from six countries and it is interesting that the proceedings were edited by another father of photogrammetry, Prof. Otto von Gruber. The course continued annually in Jena until 1913. It was not until 1929 that von Gruber organized the 6th course, which attracted 41 participants from 14 countries. The pattern continued and the 20th course took place, still in Jena, in 1940. The term "Photogrammetric Week" was coined in 1937. After another interruption, the 21st Photogrammetric Week took place in Munich in 1951, though there were only 28 participants—nevertheless the US was represented! A preference emerged to team with universities, so the 21st to 29th events were in Munich from 1951 to 1963, then the next four, from 1965 to 1971, in Karlsruhe, with an average attendance of 160. The event moved to Stuttgart in 1973 and has continued there biennially, with attendances rising to over 500 photogrammetrists from academia, government and industry all over the world. The traditions of the event—invited papers in the mornings; demos by exhibitors in the afternoons, for which a rota is provided so that every participant is able to see every demo; evening receptions in the University and the Town Hall; conference dinner in a beautiful rural location—are strong and most participants are eager to return. Merged with tradition is leading-edge technology and often the exhibitors give pre-announcements of new products to be launched at Intergeo very soon after PhoWo.



notably in rapidly growing megacities around the world due to the high demand for water from incoming dwellers and illegal or at least uncoordinated well construction. Subsidence may lead, for instance, to amplification of flooding hazards because water from a river or the sea more easily finds its way into the city and takes longer to recede.

PolSAR is especially useful for land cover classification, in particular for tasks such as crop monitoring. The lack of spectral resolution (usually only one band is used at a time) is balanced by the dense temporal sampling capability of SAR due to its independence of weather conditions, as well as far longer wavelengths compared to the visible spectrum. Many studies have been conducted, which have never really found their way from academia into commercial operation—until now. Agribusiness already begins to exploit such techniques based on PolSAR.

Except for defense applications, airborne SAR is still a kind of niche. Some private companies left the market, but there are others performing quite well. I think there are some applications that benefit from the higher ground coverage per time unit.

Finally, I believe SAR is on track for a bright future. In 2014 Europe started its Copernicus constellation purposefully with the launch of Sentinel-1, a SAR satellite. Other players in the world are continuing their programs too, for example, Japan and China. I am eager to learn the decision of Germany's government on the direction of the national SAR program, scheduled to be announced in the first half of next year.

> "SAR interferometry, including advanced variations such as differential interferometry (dInSAR) and persistent scatterer interferometry (PSI), are the hot topics of radar remote sensing."

LM: One of the messages from papers and demonstrations at the Photogrammetric Week was an acceptance that technologies are complementary rather than competitive. No longer are people arguing that we don't need LIDAR because photogrammetrically derived elevation data is so good—or *vice versa*! How do you see the complementary roles of photogrammetry, LIDAR and SAR for the generation of elevation information and the detection of changes of elevation through time? Also, airborne LIDAR data is being combined with LIDAR data from mobile mapping systems and terrestrial laser scanners: this is a powerful approach to the generation of information, but do you feel that the different error characteristics of these technologies are taken sufficiently into account during the data merge?

Sörgel: I have made the same observation. Photogrammetry and laser scanning are complementary rather than competitive. There is a clear trend to use the technologies together, even simultaneously with cameras and sensor devices mounted on same airborne or terrestrial platform. In this way, LIDAR mitigates the shortcomings of image-based elevation models, for instance, blur at steep edges such as building facades or in vegetated areas. On the other hand, in contrast to LIDAR, images provide spectral resolution and sharper object boundaries. In addition, radar plays a role here: car manufacturers use cameras, laser scanners for close range and radar for long range and in case of fog or rain. Today the latter is still restricted to diffraction-limited real aperture radar, i.e., used for scanning not for SAR imaging yet. You mentioned the necessity of proper error modelling for such fusion. This is indeed currently a hot topic of research conducted also at ifp.

We have already discussed the successful SAR-based missions SRTM and TanDEM-X, providing global DEMs of unprecedented quality. The main shortcoming of SAR, however, is its restriction to side-looking viewing geometry, leading to undesirable effects such as layover and occlusions before and behind elevated objects, respectively. This is why for routine mapping of cities SAR is not the first choice and we should better rely on techniques capable of imaging or scanning in the nadir direction. Nevertheless, in the case of disaster or crisis, SAR may be the only means of rapid mapping required for quick response. As soon as we turn to rural or natural scenes, there are scenarios where airborne SAR is very useful: radar of long wavelengths such as L- or P-band can penetrate even very dense vegetation such as rain forest. Another example is coastal areas and river beds, which often require monitoring of vast areas on a regular basis; depending on scene characteristics, in such scenarios airborne InSAR can be more efficient than LIDAR.

LM: Our readership, of course, is primarily involved in LIDAR, which is central in the teaching and research going on in ifp as well as in the lectures and demonstrations at the Photogrammetric Week. We are all trying to understand and evaluate the new airborne LIDAR technologies that have entered the non-military mapping world in the last few years, such as Geiger-mode and single-photon LIDAR. The review paper at the Photogrammetric Week by Professor Jutzi from Karlsruhe. provided insightful, dispassionate guidance. Meanwhile, the suppliers of "traditional" or "linear mode" airborne LIDAR systems continue to refine their offerings with spectacular developments such as full waveform, multispectral and topobathymetric LIDAR. How will the new and established technologies play alongside each other and how do you see LIDAR and its applications evolving? What about LIDAR from drones?

Sörgel: I was delighted to learn how innovative the LIDAR industry has become today. From the engineering point of view, Geiger-mode and single-photon LIDAR are very interesting techniques. In my opinion, we are dealing again here with complementarity rather than competition, leaving room for these new technologies and conventional "linear mode" airborne LIDAR. The former are more efficient in terms of ground coverage, whereas the latter provides higher accuracy and precision of the 3D point cloud.

I am convinced that LIDAR on drones will become somewhat standard. On the one hand, small laser scanning devices tailored for such platforms have already entered the market, whereas, on the other hand, regulations in some jurisdictions have become relaxed (e.g., recently for some applications in Germany, the weight limit for UAVs was lifted from 5 kg to 10 kg), which allows the use of heavier devices. Multispectral LIDAR will definitely improve land cover classification down to species recognition of individual plants. Finally, laser bathymetry is meanwhile the first choice in coastal areas of low turbidity, complementing ship-based echo sounding focusing on deeper and muddy waters.

> "Photogrammetry and laser scanning are complementary rather than competitive. There is a clear trend to use the technologies together, even simultaneously with cameras and sensor devices mounted on same airborne or terrestrial platform."

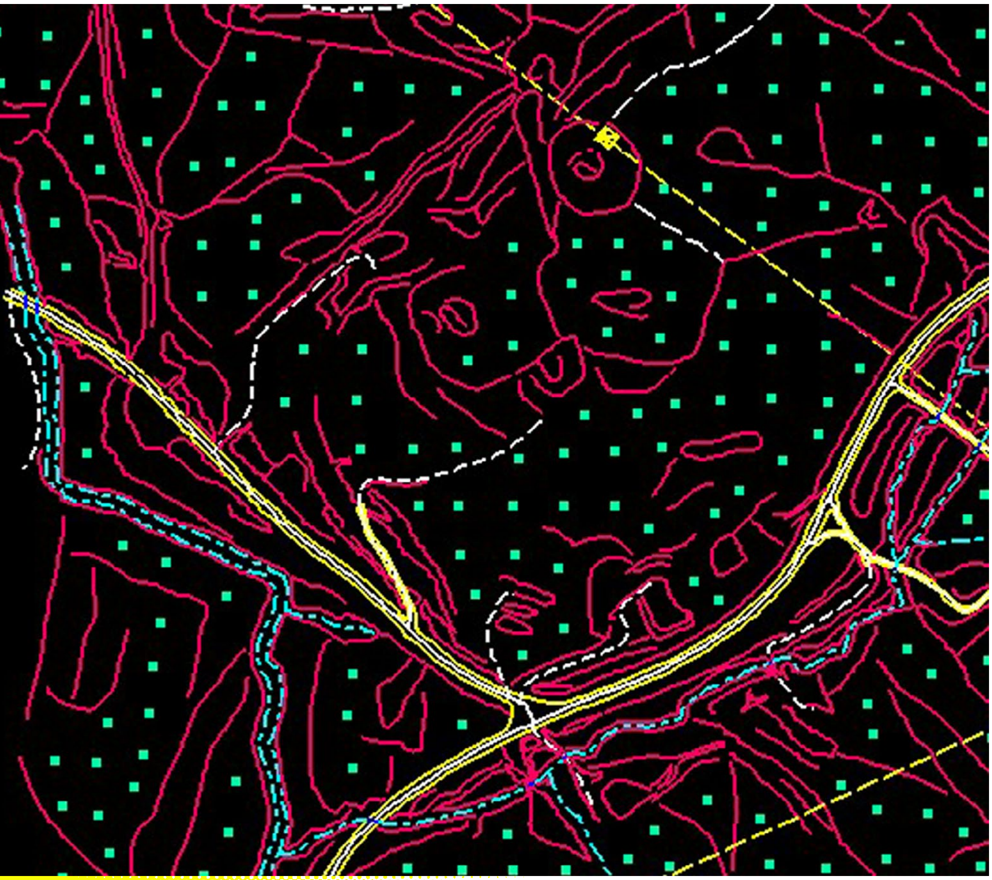
LM: This year's Photogrammetric Week included numerous stimulating sessions: we heard about new airborne SAR and hyperspectral sensors; we learned about the role of photogrammetry and LIDAR in autonomous driving, precision agriculture and building information modeling. Would you like to try to predict the most significant developments in the near future, say two to five years?

Sörgel: Well, I think it was Mark Twain who said: "It is difficult to make predictions, particularly about the future." Nevertheless, I dare to share my thoughts about the near future to some extent. I believe that deep learning techniques such as convolutional neural networks will play an important role for 3D point cloud processing and analysis too. In addition, fusion of oblique imagery and LIDAR will become a standard set-up at least for urban mapping.

LM: Professor Sörgel, thank you very much indeed. *LIDAR Magazine* is grateful for your responses and wishes you a long, successful tenure as the chair of ifp.

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

Should Contours Be Generated from Lidar Data, and Are Breaklines Required?



This image illustrates traditional photogrammetric terrain modeling with breaklines and mass points. The generation of breaklines is time consuming and can yield more appealing contours at road edges or other sharp breaks in the terrain, but breaklines will not add to the accuracy or the quality of the contours when using a dense lidar dataset.
Courtesy of Woolpert

BY DR. QASSIM A. **ABDULLAH**

Lidar data provides the most accurate and reliable representation of the topography of the earth. As lidar technology advances and point clouds continue to become richer and denser, elements of lidar collections that once were necessary to the process naturally phase out.

However, government agencies and other users contracting for lidar data often additionally request specific outdated mapping components, not realizing that these additions cost them unnecessary time and money. These mapping components include contours generated from lidar data, and the use of breaklines to support lidar data.

Understanding why these mapping components were developed, what roles they once played and what roles they can play in modern lidar applications will help agencies decide whether to request their inclusion.

History and Application of Contours and Breaklines

For centuries contour lines, which connect places of equal elevation, were the most common way to numerically represent land elevation and topography on paper or hard-surface maps. When they were developed, it was not practical for land surveyors to manually record relief, so a limited number of spot elevations were surveyed.


Imagine flying through your workday
Perimeter: 108.03 m
Area: 886.11 m2
Cut volume: 2263.65 m3
Fill volume: 15.35 ppm3
With precision hi-res imaging and accurate mapping, the Intel® Falcon™ 8+ Drone – Topcon Edition* will help you quickly soar through projects.
TOPCON
See your projects take flight:
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*May not yet be available in all markets
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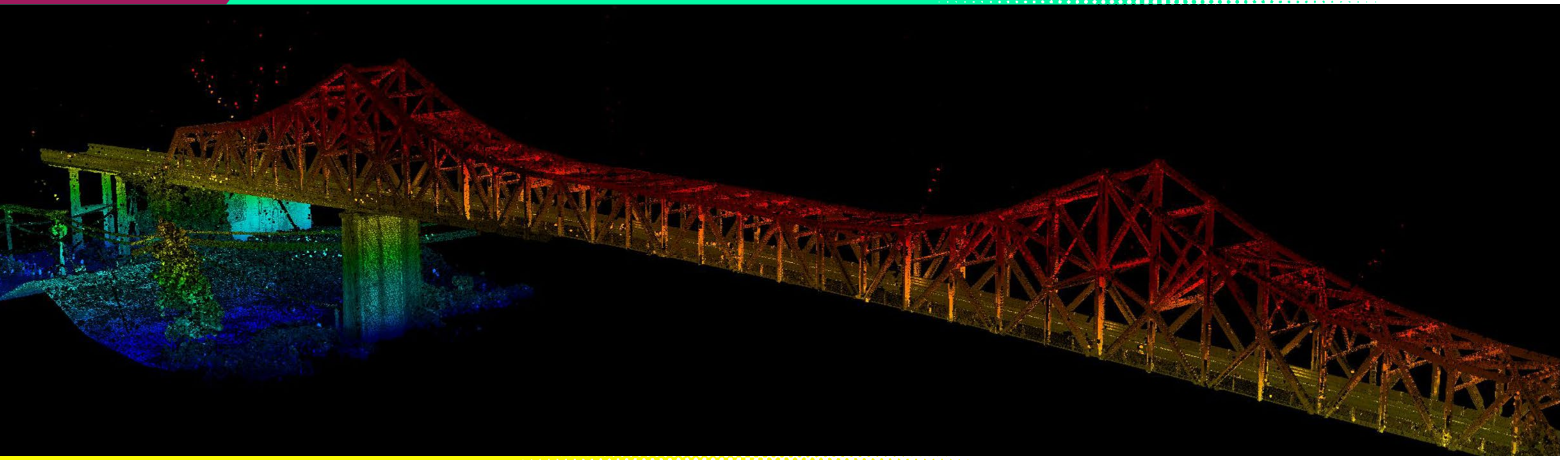


The Clarendon Bridge spans the White River at U.S. Highway 79 in Monroe County, Ark. This image shows static lidar modeling.
Courtesy of the Arkansas Department of Transportation

The U.S. Geological Survey (USGS) produced the first topographical survey maps that included contour representation of terrain relief, and this paved the way to soft copy, digital modeling and representation of land topography, and diminished the need for contour lines.

The use of breaklines evolved as the digital mapping industry matured. Breaklines, developed using photogrammetric stereo-compilation, are three-dimensional lines in a digital mapping environment. They were introduced to more accurately capture changes in terrain in the presence of sparse 3D points, sometimes called "mass points," or what we refer to today as point clouds.

Since it's not economically feasible to trace the ground and generate height information for every square foot of land through the 3D digitization process, the industry devised the breakline approach to ease the labor-intensive and expensive map-making process.

As digital map-making moved forward, terrain topographies were modeled by pulling contours. An operator would fix a floating mark at a contour elevation and manually digitize the terrain where the elevation was equal to the set contour elevation.

This process was replaced by what is sometimes is referred to as a digital terrain model (DTM). DTMs usually contain course mass points that represent terrain elevation in flat and rolling terrain, and breaklines to represent abrupt changes in the terrain. The mass points and vertices of the breaklines are converted to a triangular irregular network (TIN), from which contours and other terrain models are derived in a digital environment.

These initial mass points were far less frequent and dense than today's lidar point clouds. This density depends on map scale and the relief in the terrain. Collecting mass points with post spacing of 50 feet to 150 feet was and still is common when modeling the terrain using stereo photogrammetry.

With coarse post spacing of mass points and with the absence of breaklines, terrain modeling is less accurate because it fails to represent the true shape of the terrain.

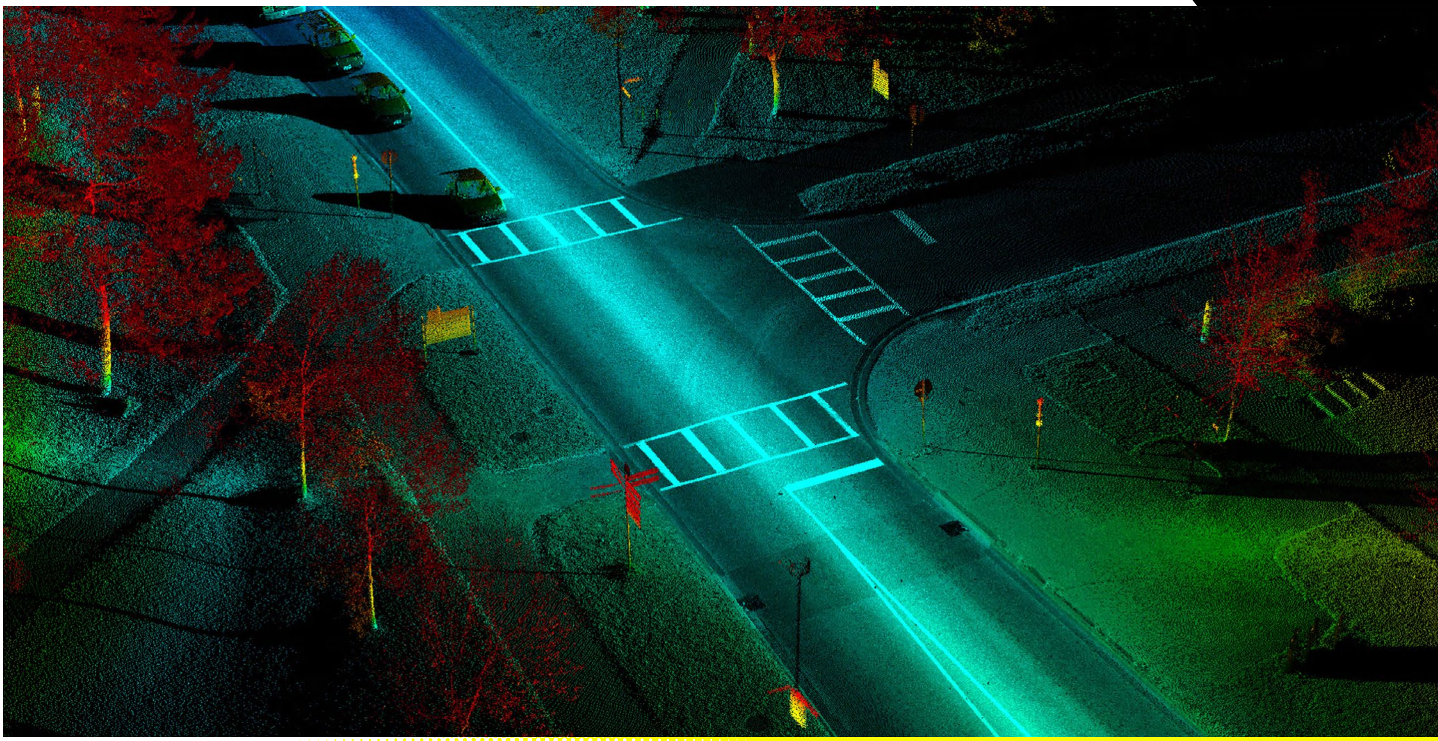
Enter Lidar Technology

When lidar technology started taking off in the mid-1990s, pulse repetition rate—which contributed to the point cloud density—was very low. Collecting a lidar-based point cloud with a post spacing of 5 meters was a normal practice at the time, improving to a post spacing of 2 meters a few years later and steadily increasing in density over time.

Today, the industry is collecting USGS Quality Level 2 (QL2) lidar data with a density of 2 points per square meter and a post spacing of around 0.71 meter (or 2.3 feet). Soon, Quality Level 1 (QL1) lidar data with a density of 8 points per square meter and a post spacing of around 0.35 meters (or 1.15 feet) will be the norm within the industry.

Lidar point clouds, which provide an elevation post down to each foot of the terrain, provide the most comprehensive method of modeling terrain.

Contours are generated by the subsampling, or thinning, of dense lidar data. This process takes valuable labor hours to produce, and creates a product



Providing breaklines with mobile mapping system (MMS) data, as modeled in this image, allows for the reduction of delivered data and enables the modeling software to handle it more efficiently. However, lidar points from MMS alone are sufficient for any type of 3D modeling if the modeling software matures to handle the amount of data necessary.

that effectively hides valuable information about the terrain elevation in the point cloud.

Contours generated from the DTM, like breaklines and mass points, are smooth, as the contours are interpolated from mass points (and breaklines, if they exist) with post spacing of 50 feet or more. Such wide spacing of mass points smooths the interpolated contours, as it is less sensitive to the micro changes in elevation across the terrain.

On the contrary, lidar point clouds, because of their high density, are very sensitive to changes in elevation, so contours generated from lidar do not look appealing. However, such contours are more accurate in representing the terrain than the photogrammetric contours.

For most applications, when using a USGS QL2 lidar dataset, breaklines do not need to be added due to the high density of the point cloud. Breaklines are only needed in the absence of a dense point cloud, as was the case with the photogrammetric modeling of terrain.

Although breaklines can yield more appealing contours at road edges and other sharp breaks in the terrain, they will not add to the accuracy or the quality of the contours when using a dense lidar dataset.

Many software applications expect lidar points not to fluctuate, even within the noise limit or accuracy of the lidar data and when used with down-slope flow modeling. That is the only reason the massive modeling of breaklines is added—to represent linear water features and to assure a smooth and enforced downhill flow.

Modeling software companies can help the industry and reduce project cost if they would implement a tolerance of elevation fluctuation to within the repeatability of the lidar point cloud, which is specified in the USGS lidar base specifications to be around 6 centimeters.

Some agencies specify breakline compilation solely for hydro flattening of water bodies, but most of the time this is done for aesthetic reasons. Users of lidar data should accept that lidar data is dense, and there always will be an unevenness in the surface due to the random errors in the data represented by the repeatability of lidar data, which in most cases amounts to within 6 centimeters.

By accepting that lake surfaces do not need to look completely flat in a lidar dataset, it could save hundreds if not thousands of hours flattening such surfaces.

Even for volumetric computations, such unevenness of lidar data will not compromise the volume computations' accuracy. Such fluctuation is random and occurs around the mean terrain elevation, assuming all biases are removed from the lidar dataset.

Where Breaklines and Automated Contours Have Value

Although breaklines don't play the key role they once did, until processes and modeling software change, collecting breaklines from a dense lidar dataset still has useful applications in specific cases.

Breaklines are beneficial in defining obscured drainage lines in vegetated areas, a practice which can be inaccurate if generated by lidar points alone, and in the identification of free-standing walls, like sound barriers or retaining walls around bridge approaches.

But most often, the use of breaklines is applicable in road design and engineering, as departments of transportation (DOTs) require precise delineation of edge of pavement, road crown, curbs and gutter lines, top and base of curves, and other elements of the road.

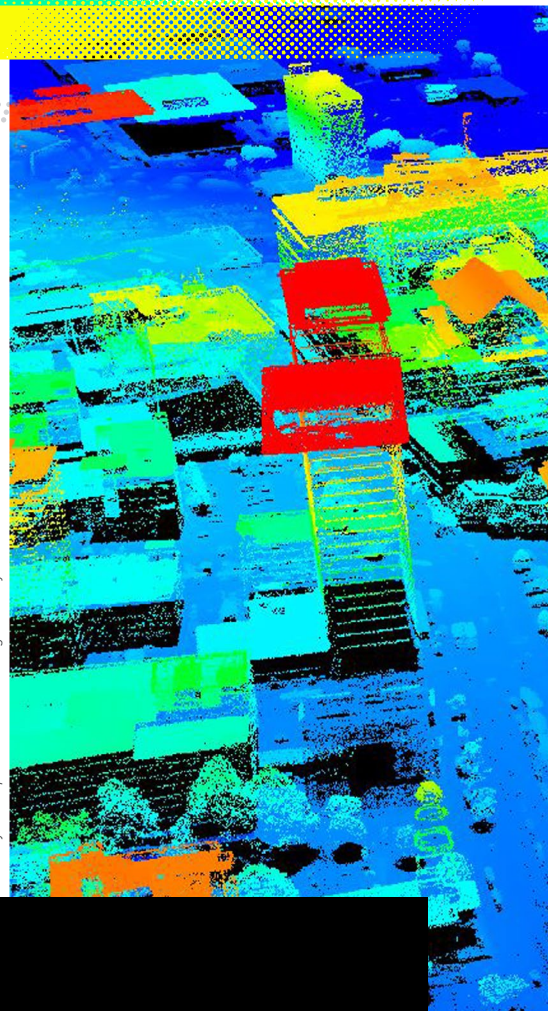
Current capabilities of aerial lidar collection do not allow engineers to accurately determine these lines from lidar, therefore manually collected breaklines are needed to complete DOT road engineering activities.

Also, providing breaklines with mobile mapping system (MMS) data allows for the reduction in size of delivered data so modeling software can handle it more efficiently. In many cases, the full density of the MMS data is used to extract breaklines after which the data is decimated to a 3-foot grid and delivered with the breaklines to be used within the modeling/CAD software.

As computing power and the ability to store and readily access these massive amounts of data advance, however, the reliance on breaklines in road design and engineering also will diminish.

If the end user requires breaklines to augment lidar data and if the accuracy requirement allows, there is a less expensive approach to extract breaklines, and that is automated breaklines.

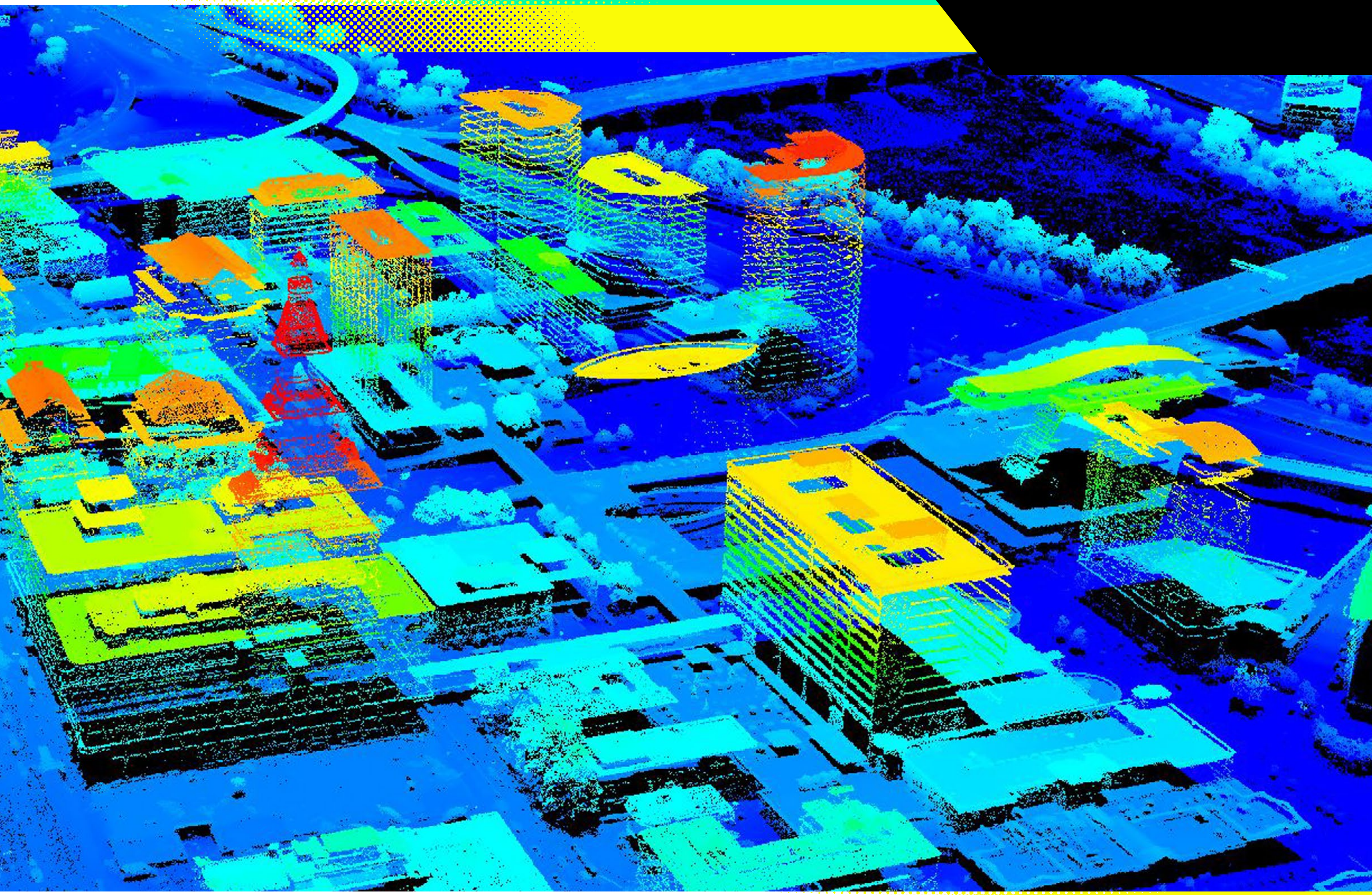
For automated breaklines, lidar point clouds and lidar intensity and/or existing imagery can be used through image segmentation techniques to extract edges that can be used as breaklines. This is a work in progress, but is one that bears pursuing.



Courtesy of Woolpert and the U.S. Geological Survey

Courtesy of Woolpert and the U.S. Geological Survey

This dense aerial lidar modeling of Hartford, Conn., was generated through the use of single-photon lidar.



This alternative view of Hartford, Conn., also illustrates a dense, aerial collection using single photon lidar.

If contours are desired, users should know that contours generated from lidar are more accurate and make a better representation of the terrain than the contours generated from DTM.

When contours are generated from elevation posts spaced every 35 or 71 centimeters, the maximum length of the triangular sides of the generated TIN always will be less than 100 centimeters. This is not the case with the photogrammetric-derived contours modeled from DTM with triangular sides exceeding tens of feet in length.

Contours generated from a lidar dataset appear jagged because lidar is more sensitive to the changes in terrain. Lidar-based contours can be described as "hypersensitive" due to the wealth of elevation details they carry.

Contours will have the accuracy of the lidar data and will reflect nearly the actual elevation of the lidar point cloud at the location where these contours are plotted.

However, contours in general do not represent the lidar data quality, as the lidar point cloud provides better details about the relief than the contours alone, unless the contours are created with a 5- to 10-centimeter contour interval.

Evaluating Need Will Save Time, Money

The mapping industry is evolving quickly and can seem like a moving target for those outside the industry. That is why, whenever possible, these changes in the technological process and application should be shared—even if this creates a short-term financial loss for the lidar data provider.

By being aware of these advances and their ramifications, government agencies can request and receive the best and most appropriate lidar data for their statewide or countywide mapping projects, and save time and money in the process.

Dr. Qassim A. Abdullah, Ph.D, PLS, CP, is Chief Scientist, Geospatial Services and Associate at Woolpert.

SHOULD I STAY, OR SHOULD I GO?

Manned LIDAR versus Drone LIDAR

One of PrecisionHawk's LIDAR sensors Mounted on a Dji M600 used for Crop Analysis

BY JAMIE YOUNG

Manned LIDAR has been widely used for roughly 20 year and Drone LIDAR recently has become a new tool in the Geonerd toolbox but are you just using it because its cool? When is it a good time to use Drone LIDAR or should you continue to use manned LIDAR? Is Drone LIDAR better? When is Drone LIDAR better? Is Drone LIDAR cheaper? What can I do with Drone LIDAR that I can't do with manned LIDAR? All these questions are very good questions but just because it's a Drone and a Drone LIDAR doesn't mean it is a lesser product or should be less expensive or more expensive.

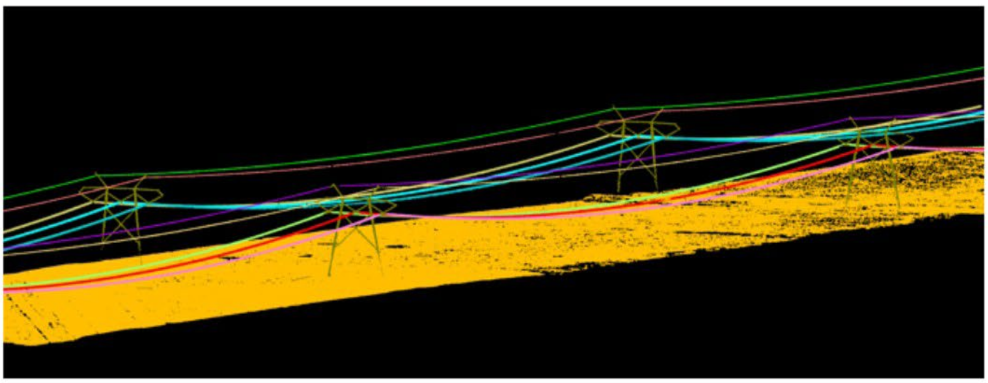
The comparison of Drone LIDAR versus Manned LIDAR should be discussed. The only real similarity is Manned LIDAR uses much more expensive components and yields similar results but there are distinct differences. The Drone Sensors are smaller, operate on smaller platforms and require a smaller wallet thus the intended project areas will be smaller. At some point to collect a project with a Drone becomes less efficient but the data density will be much greater. Drone LIDAR can also facilitate the collection of very accuracy dense data within a larger project collected with manned LIDAR.

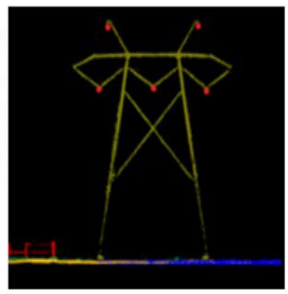
The differences

The differences as they relate to the functionality and what the sensors can yield are obvious to the sensor operators but may not be as obvious to the end users. Basically, The Drone LIDAR operate at roughly 40 to 100m above ground. The Riegl Mini-Vux-UAV sensors are capable of operating at higher altitudes,

Riegl MiniVux-UAV mounted on a Riegl Ricopter, similar to one of PrecisionHawk Mini-Vux-UAV.
Provided by Riegl USA

Row #	Structure Number	Station (m)	Height Adjust. (m)	X Easting (m)	Y Northing (m)	Centerline Z Elevation (m)	TIN Z Elevation (m)	Ahead Span (m)	Line Angle (deg)	Sets In XY Structure Line Angle Calculation	Transverse Axis Azimuth (deg)	Structure Name	Structure Description	Struct. Height (ft)
1	TFPL-007	272.2514	35.08	546508.46	3001724.36	38.7	38.7	350.3	0.4446	NM	276.1181	1_s1s3p0c.#1	Complete Tower	35.08
1	TFPL-008	650.5929	34.78	546501.91	3001353.6	41.88	41.88	448.98	-4.1582	NM	274.039	2_p1s3p0c.#2	Complete Tower	34.78
2	TFPL -009	271.374	34.92	546596.91	3001730.01	38.25	38.25	353.78	0.9516	NM	272.4357	3_d1s3p1c.#3	Complete Tower	34.92
2	TFPL-010	651.664	34.69	546589.14	300134.92	41.22	41.22	450.7	0.6086	NM	273.2158	4_s1s3p1c.#4	Complete Tower	34.69

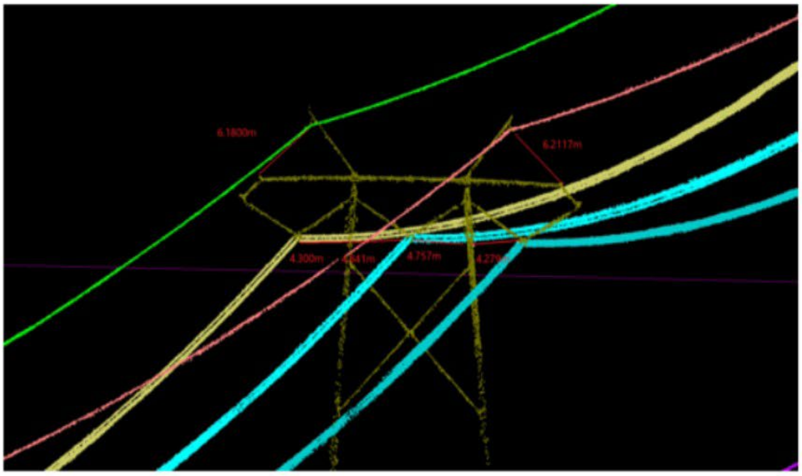




PrecisionHawk Transmission Analysis Report and Data Examples from Drone LIDAR

but current FAA restrictions prevent the operation of Drones above 500 feet. The fixed wing manned LIDARs, depending on application operate at much higher altitudes and the average operating altitude is between 1000 to 2000m AGL. Please note that this doesn't include Geiger Mode LIDAR which operates at significantly higher attitudes and Helicopter LIDAR that operate at much lower altitudes then Fixed wing LIDARs. Exact altitudes can be deduced from providers that operate a certain type of sensor and platform. The point density for Drone LIDAR will range roughly between 50 PPM at the low end to 500 PPM at the high end and manned LIDAR ranges between 1 PPM to 150 PPM. Please note that these point density ranges are not written in stone and are rough estimates bases on general guidelines. The point density is a function of several flight characteristics such as LIDAR point repeatability and AOI characteristics, such as man-made, vegetation and relief characteristics. Honestly, any LIDAR sensor can be flown to get any point density, it just becomes impractical at some point. The stated accuracy in general for Drone LIDAR depending on the sensor and processing, will range between 1.5 cm – 9 cm RMSE and potentially the accuracy could be a little better depending on survey and process but realistically you can expect these stated accuracies economically. Manned LIDAR accuracy typically is between 2cm -10cm RMSE and this includes helicopter applications. The fixed wing sensor can typically achieve between 6 and 10cm RMSE economically. Helicopter sensors are between 2 to 6cm RMSE. Currently, Drone LIDAR project area size as it relates to being most economical would range between 6 to 10 square miles or smaller. Manned LIDAR Project traditionally ranged between 1 square miles to several thousand square miles. Typically, Drones LIDARs can collect between 15 to 40 linear miles a day depending on the system and Drone. Helicopters can

Tower	Easting	Northing	clearance (S1) m	clearance (S2) m	clearance (S3) m	clearance (S4) m	clearance (S5) m	clearance (S6) m
TFPL -10	546590.95	3001347.77	6.2114	6.08	4.3	4.27	4.8413	4.7575



PrecisionHawk Structure Clearance Report and Data

do more but the points density is not as dense. This is a comparison similar, to the relationship of fixed wing LIDAR point density versus Helicopter LIDAR point density.

How to determine which should be used?

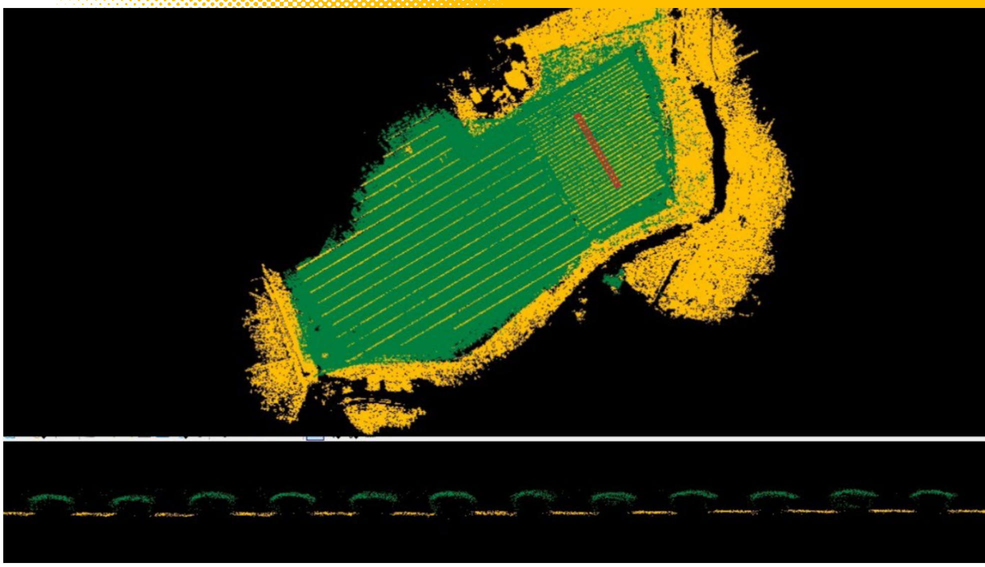
This is very hard to generalize, and each project should be carefully evaluated for what sensor approach should be used. This can be compounded by the characteristics of the sensors such as number of returns per pulse. This is important because current Drone LIDAR sensors range between 2 returns per pulse, up to 5 returns per plus, whereas Manned LIDAR can report several returns per pulse. Geiger and photon LIDAR sensors operate differently making this a non-issue.

Basically, the following questions should be asked to determine if Drone LIDAR or Manned LIDAR should be used. What is the size of the project being mapped? The general rule of thumb was answered above. How many areas do you want to map as they relate to the size of each area? Several extremely small areas would probably be best mapped with a Drone LIDAR. What features are you mapping? and How much detail do you want to get? Drone LIDAR (roughly 50 to 500 PPM) achieves significant detail. The algorithms that can be run on this level of detail definition can yield features, common to mobile mapping detail. The features such as individual walls, cars, trees, and other detail features can be extracted. Additionally, small scale routine LIDAR collections on changing natural features and man-made structures can be mapped with drone effectively and economically. Large projects with smaller areas requiring very dense collection within the large project potentially could be done with drone LIDAR to limit the cost as it relates to using another platform.

One developing Drone LIDAR technology is bathymetric LIDAR. This is an extremely exciting application because historically bathymetric LIDAR projects are much smaller than topographic LIDAR projects. Additionally, these projects are isolated to small water bodies and streams. The vegetation and terrain characteristics around water bodies and streams can be extremely challenging making Drone Bathymetric LIDAR, the best solution for this application. Additionally, weather conditions and atmospheric conditions around water present additional challenges for the Manned LIDAR approach makes the Drone approach more economical.

Cheaper LIDAR

Drone LIDAR can be less expensive then Manned LIDAR for small project areas and as stated the economic benefit of Drone LIDAR diminishes at some point based on the size of the project. The importance of understanding the meaning of less expensive means it is key to this discussion. Yes, it is less expensive to fly Drones for small projects as it relates to the basic product understanding of LIDAR data. There is a significant benefit of the Drone LIDAR technology, as it relates to the accuracy of the data and the much lower flying height of the platform and the significant increase of point density. Additionally, advances in Drone LIDAR technology, as it relates to flying height, limited to the airspace operating altitude will further reduce the cost of Drone LIDAR. Much like the increased repetition rates of manned systems, resulting from increased flying heights, the cost of manned LIDAR was reduced. The actual point density as it related to the actual specified point density is much greater than required with Drone LIDAR. Drones LIDAR will be collected at roughly a minimum 50 PPM at the highest possible flying height regardless of required specified point density.



Classified LIDAR for crop Analytics **Top view:** classified Drone LIDAR by ground and Crop **Bottom view:** profile of the crop verses Ground as located by the red profile line in the top view

In most case the collection of Drone LIDAR will be less expensive or in some cases equal to Manned LIDAR, but the entire project delivery and specification needs to be considered. In simple terms the more you get, the more it will cost. Given the resolution and definition of the Drone LIDAR data, there is more value in the data set based on that definition. Additionally, similar too manned LIDAR, there is a cost associated to what is extracted from the data, which can be much more information from Drone LIDAR.

What is needed and what technology should be used?

In several previous articles by this author it has been reiterated the need to understand what problems are to be solved and what solutions are required for a given application? Additionally, there are potential additional uses for the data as it relates to applications that were not realized previously by both the user and provider. Commonly, a given project collection and application results in the end user discovering additional uses for the data. The reason why this is usually recognized by the end user is because they usually have much more experience with their application. This is much more obvious during the initial evolution stages of an emerging technology such as Drone LIDAR. It is very important to understand that just because a given specialized LIDAR technology is being presented by a company that specializes in that given LIDAR technology, doesn't mean it is the best technology for a given application.

Drone LIDAR provides a valuable tool for solving problems and providing solution because of the increased point density, feature definition and improved accuracy that doesn't currently exist with manned sensors. Again, this is a welcomed addition to the Geonerd Toolbox and it has its place in the geospatial profession. The resulting decreased operation cost continues to provide less expensive solutions to professionals that would not otherwise be able to procure LIDAR data. This is especially prevalent in smaller project as it applies to both topographic LIDAR and Bathymetric LIDAR or a combination of both. Added value can also be recognized with the addition of other remoted sensed data such as RBG, Multispectral, Thermal and Hyperspectral data.

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

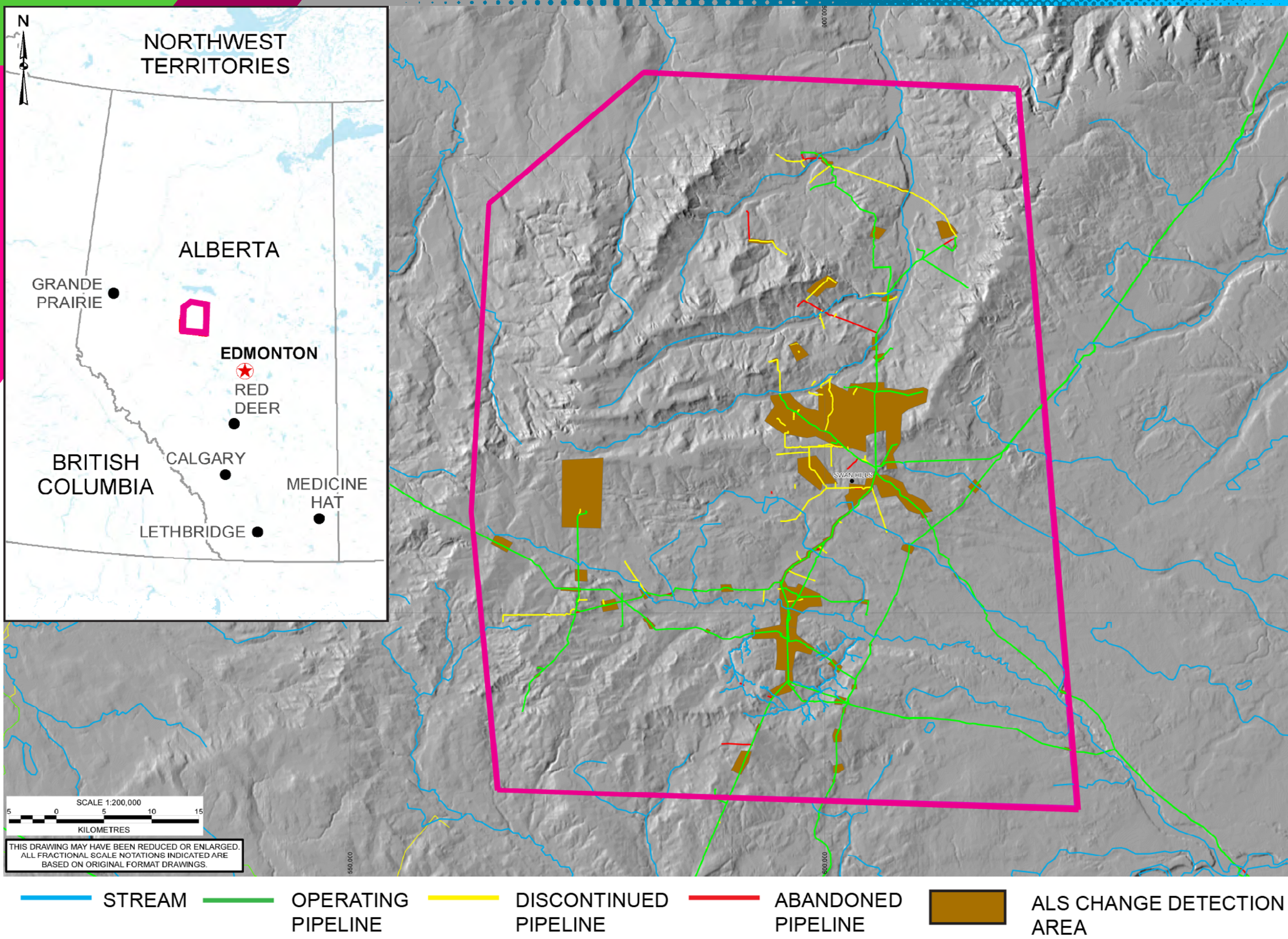


Figure 1: The Swan Hills study area in Alberta. Areas where ALS change detection was completed are shown.

Utilizing Temporal Airborne LiDAR to Identify and Characterize Pipeline Geohazards

BY MEGAN **VAN VEEN**

BGC Engineering Inc. (BGC) is an applied earth sciences consulting firm with offices across Canada as well as in the United States and Chile. BGC works to aid our pipeline clients in managing a variety of geotechnical and hydrotechnical hazards, employing a systematic approach to prioritize sites for inspection, monitoring, and mitigation. Pembina Pipeline Corporation (Pembina) owns and operates over 500 km of oil pipelines in the Swan Hills region of Alberta (**Figure 1**). BGC has been working with Pembina since 2007 to manage risks posed by geohazards to the safe operation of their pipeline network. The geotechnically challenging terrain in this area presents a significant inventory of geohazards

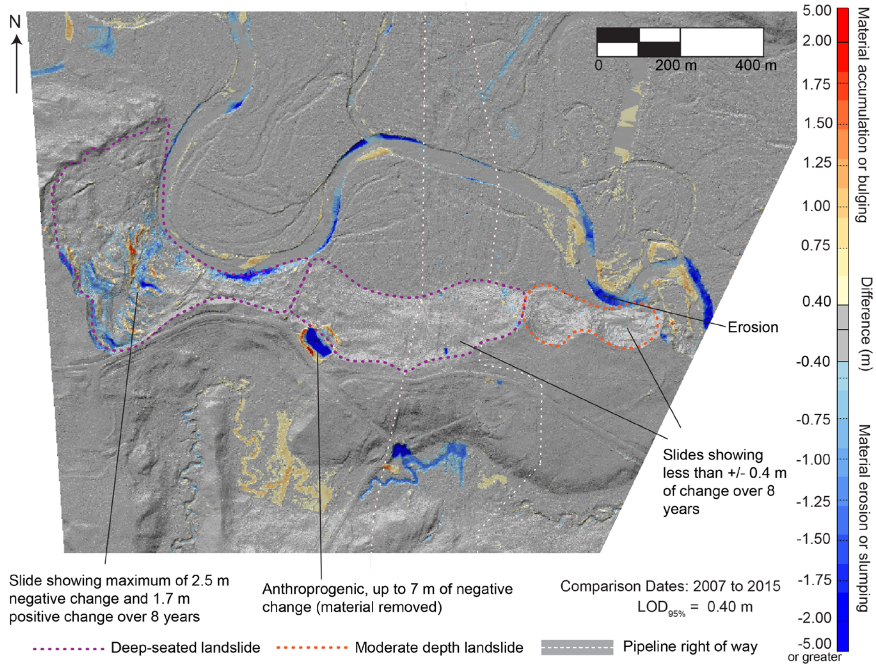


Figure 2: Sample change detection map showing landslide movement, stream bank erosion, and anthropogenic changes between 2007 and 2015

> "The use of ALS change detection can provide insight into slide activity, which is a critical component of geohazard characterization…"

including deep-seated landslides in bedrock, shallow to moderate depth slides and slumps within surficial soils, and stream bank erosion. Working with Pembina, BGC utilized multi-temporal Airborne Laser Scanning (ALS) data to perform topographical change detection analyses, to assist in identifying and characterizing geohazards and recognizing anthropogenic changes within, or in proximity to, the pipeline rights-of-way. BGC has used this tool as input to a screening process to prioritize sites for detailed field inspection. We also present a case in which ALS change detection was used as an immediate response to develop mitigation strategies for a pipe that had become exposed to an active landslide.

The use of ALS change detection can provide insight into slide activity, which is a critical component of geohazard characterization that is often difficult to evaluate using traditional methods. While a single ALS data acquisition is useful in identifying landforms with slide morphology, it does not provide information about slide activity, extent or changes to the topography. ALS change detection can provide positive confirmation of slide activity, and can be used to identify where active slides are noted to be impacting a pipeline. This information can be used to update the frequency of geohazard inspection or monitoring activities. Another advantage of ALS change detection is the ability to use the results as a preliminary screening tool to identify and characterize geohazards across spatially expansive regions. This analysis also allows us to identify small changes that have accumulated over several years that may not be evident from field inspections.

In this case study, BGC inspected sixty areas within a 4,800 square kilometer area of interest, covering 481 previously identified geotechnical hazards, in a period of three weeks. The analysis was used as part of a screening tool to help make more informed decisions as to which sites are in need of detailed field inspections. 2006, 2007 and 2008 ALS data were compared to 2013 and 2015 data. The quality of data was variable. 2006 to 2008 data were available as 1 m elevation grids or point clouds with an approximate density of 1.1 points per m^2. Point clouds for the 2013 and 2015 data had an approximate density of 2.2 points per m^2.

To perform the change detection, BGC employs sophisticated three-dimensional (3D) processing methods that maximize the information gained from the analysis and accurately quantify the reliability of the results. Using these methods, we have been able to detect ground changes as small as 20 cm in this area over a period of eight years. In order to account for the slight misalignments that exist between different ALS datasets, due to georeferencing errors during data collection, BGC employs a 'fine realignment', which adjusts the position of the ALS datasets relative to another by applying a translational and rotational shift to one dataset, which minimizes distances between the two datasets. To improve the quality of the alignment, this process is only performed in areas that are known to have been unchanged between the surveys. The limit of detectable change (LOD) is then determined for each site, based on the alignment error between the non-changing regions in the two ALS datasets. The LOD ranged from 0.20 to 0.50 m, with an average of 0.30 m for the sites analyzed in this study.

The results of the change detection analysis are typically shown as color-contoured 3D datasets illustrating positive and negative displacements (**Figure 2**). Positive displacements are interpreted to represent accumulation or bulging of material (for example, at the toe of a landslide). Negative changes are interpreted as loss of material through geological processes such as erosion or slumping, or material removal (anthropogenic). Anthropogenic changes are often seen when construction activities take place such as grading of the pipeline right-of-way. The detailed 3D processing methods BGC employs, and our ability to quantify the accuracy of our measurements allows us to make interpretations about landslide movement rates based on the results of the change detection.

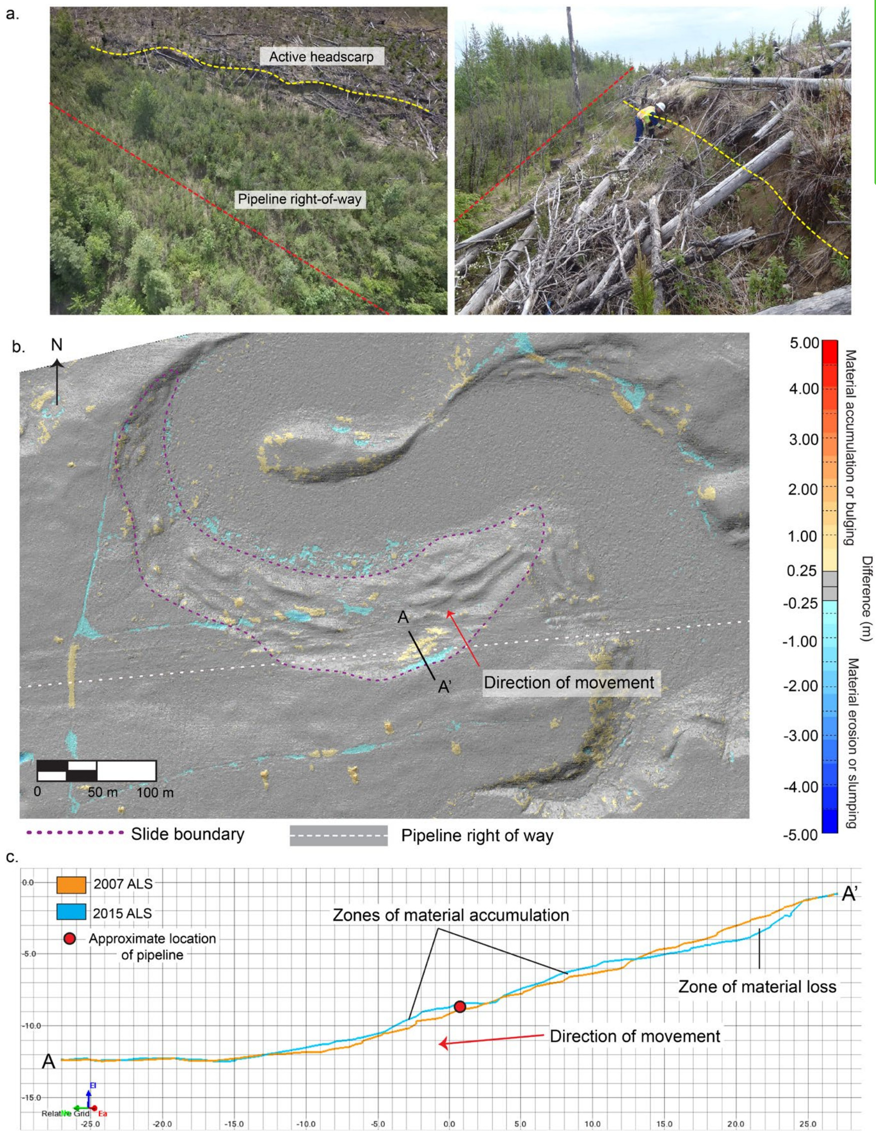


Figure 3: a) Site photos of landslide headscarp identified during a field inspection b) ALS change detection map showing landslide movement in the area where pipeline strain anomaly was noted c) profile through active landslide comparing 2007 and 2015 datasets.

Photos courtesy of Matt Lloyd and Mark Leir of BGC.

Even when no changes above the LOD are identified, this provides useful information as it is indicative that slides are moving at a rate slower than the LOD over the comparison period.

ALS change detection is useful in confirming and complementing information acquired from field inspections. The example in **Figure 3** shows an example where a landslide was noted to be impacting a pipeline. The slide area is 600 m wide and 125 m long with an approximately 120 m wide section that has been reactivated in recent years.

In 2015, a bending strain anomaly was detected over an 11 m section of pipe. A site visit was conducted in 2016, where a well-defined headscarp as well as tension cracks were observed upslope of the pipeline. ALS change detection was then performed, which confirmed the movements identified in the field, and allowed BGC to aid Pembina in defining the extents and geometry of the active portion of the slide area. The location at which ground movement and slide features were identified in the field matched with the area of largest change identified in the ALS data. The change detection map shows a downward movement of the uppermost block of the slide, with accumulation of material downslope, which can be interpreted as horizontal translation of the slide's downslope face. This information was used to develop short and long-term mitigation strategies. In the short term, the affected area of the pipeline was immediately stress relieved. The use of ALS change detection supported the eventual re-routing of the pipeline based on the identified footprint of the active slide area.

Interpretation of the change detection results requires an understanding of the capabilities and limitations of this analysis. BGC is continually working to improve our methods for processing ALS data and being able to quantify small ground changes with a high level of confidence. We continue to develop methods of communicating these results to our clients, working with them to develop strategies for the safe operation of their pipelines.

Megan van Veen obtained a BSc in Geological Engineering (2014) and a MASc in Geotechnical Engineering (2016) from Queen's University. She currently works at BGC Engineering as a Geotechnical Engineer and is involved in various projects related to remote sensing, geohazards and slope stability.

Note: Acknowledgements are given to Jamie Sorensen, Matt Lato, Joel Van Hove, Greg Hunchuk and Matt Lloyd from BGC for their contributions to this work and to Joel Babcock and Jan Bracic of Pembina Pipeline Corporation for their support.

FUTURE AFTER FIRE

The Renovation of the Eckhart Public Library

Here are the remains of the circulation desk area after the fire was extinguished. This is the location of the book return drop box.

In the early morning of July 2nd, 2017 3 individuals were wandering the town of Auburn, Indiana looking to cause trouble. That trouble resulted in 1 of the 3 dropping a lit 1" mortar style fire firework in the return book drop box of the Eckhart Public Library. The result was an intense fire that caused an estimated 3.4 million dollars' worth of damage to the building and its contents. The Auburn Fire Department was quickly on the scene and had the fire extinguished within 10 minutes of arriving. Even with their quick response the damage was horrific. Within a week of the fire the Auburn Police arrested Nykolas Elkin age 24 for the arson. He later admitted he placed the lit firework in the drop box; he was convicted and sentenced to 14 years in prison for the crime.

BY CHUCK **KNOX**

The Eckhart public Library was a gift from local automobile manufacturer Charles Eckhart in 1910 to the community of Auburn. It is a beautiful 2 story brick structure built in the arts and craft style. Since its inception, the Eckhart Public Library has been cherished by the Auburn community and the destruction of the interior by an act of malicious arson has been devastating to the community.

By the 1990's the library had outgrown the original brick 2 story building and an addition was designed by the Fort Wayne based architectural firm Morrison/Kattman/Menze. George Morrison's design was approved by the Library's board and the modern addition finished in 1996. It was the drop box of the 1996 addition that Nykolas Elkin placed the lit commercial grade firework. Two weeks after the July 2nd fire Knox Decorative Painting LLC (KDP) was hired to oversee the restoration of the building.

The Eckhart Public Library has long been a proponent of new technologies and this can be traced all the way back to founder Charles Eckhart. It was a new technology; the internal combustion engine, that Mr. Eckhart and his two

The original main entrance to the Eckhart Public Library.

sons, combined with the horse drawn carriages the Eckhart Carriage Company manufactured that would quickly propel the small town of Auburn to the forefront of automobile manufacturing in the early part of the 20th century. The resulting company would evolve into the very successful and innovative Auburn Automobile Company. Even today the Library's board understands the need to use and adopt new technologies. When the power of a LiDAR and photographic scan was described to the board they immediately understood its relevance to their fire damaged building. KDP recommended they hire BIMRAY to scan the interior of the building and the board unanimously agreed. The Library Board Members could clearly see that the LiDAR scan and accompanying photographic images would go a long way to solve many of the problems they were facing in the smoke and fire damaged main library.

Most pressing was the board wanted to document the current conditions of the damaged structure. The insurance policy the library has pays for the reconstruction of the building and replacement of the contents to their conditions prior to the fire. It was hoped the web viewer provided by BIMRAY could be used to make sure all the larger contents were documented. The board also wanted to use the web viewer to document the condition of the building for future generations to see the destruction and damage resulting from the fire.

The web viewer was also to be used as a tool to help with the raising of needed funds above and beyond the amount paid by the insurance policy. The true extent of the damage could be shown to potential groups wanting to donate to the restoration of the building. Cincinnati Insurance (one of the premier insurance companies of the mid-west) would pay for the restoration of the library to a

Damaged display case and some of the contents which were located near the circulation desk.

condition prior to the fire, however the library board and staff wanted to make changes to the structure. With the advent of the internet and advancing computer technology libraries function much differently today than they did 20 years

The 1st floor of the historic building suffered extensive heat and smoke damage.

ago. The library board wanted to make changes to the structures' interior that would embrace new available technologies.

With a new library design, the board saw the importance of providing a detailed LiDAR derived point cloud to MKM, the architectural firm designing the changes to the building. MKM would use the LiDAR data to provide a 3D model of the structure in its current rough condition and a 3D model of the new shiny design. The point cloud created by the LiDAR scan is turning out to be very useful. MKM used the point cloud data to draw 2D floorplans and then will use the data in a 3D design to help the library board and staff visualize just

The indoor scanning system used by Viametris in the fire damaged area of the 1st floor.

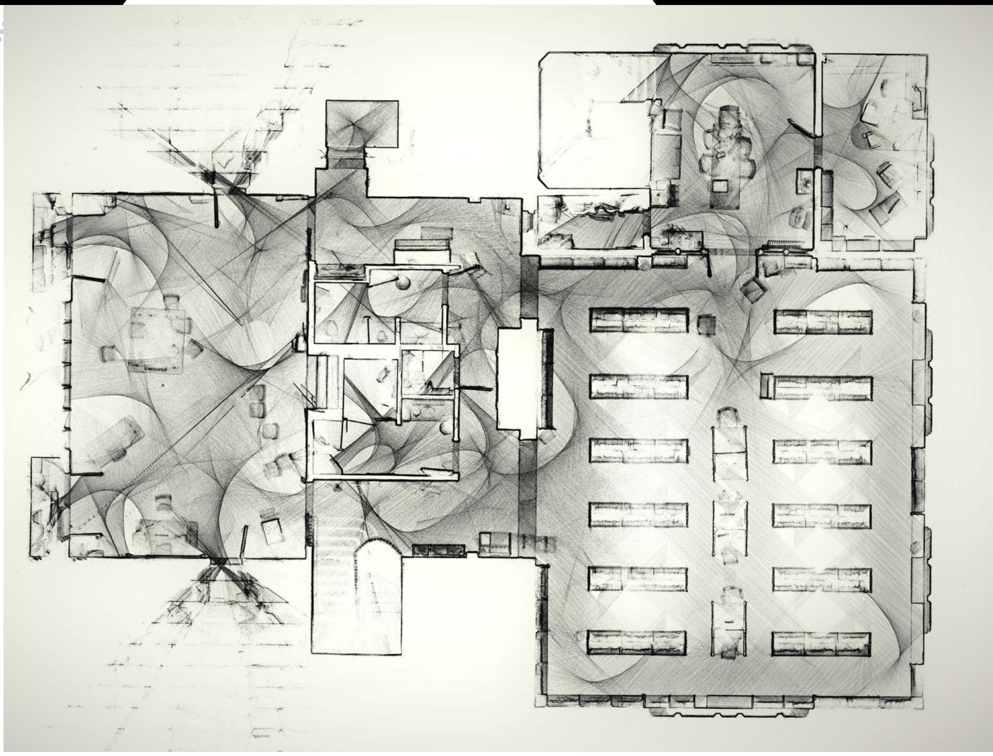
what the newly designed library will look like and how it will function.

The scan was scheduled for 8/11/17; eMAPscan arrived early in the morning with 3 technicians and equipment. eMAPscan uses the Viametris indoor mobile scanner system (iMS3D). This indoor scanning system is mounted on a rolling cart; the cart has a 360 degree camera and 3 LiDAR scanners. This rolling technology allows for the scanners to cover large amounts of square footage in very little time.

Running the scan in the damaged portion of the building would prove to be a challenge. A path through the rubble of the 1st floor needed to be cleared so the wheeled cart could be pushed through the building. Pierre Lefevre from eMAPscan planned a path through the 1st floor of the building and after planning the scan began. The basement, two floors and the exterior of the library had been scanned by noon. Library Director Janelle Graber conferred with the board and they decided that with the extra time and an available scanner an additional building should be scanned. What we have learned is that for accurate documentation of a building and its contents it is important to scan before a fire, not after.

A uniform carbon black layer of soot covering the entire 1st floor of the modern building made illumination of the damaged area a challenge. The original lights had been destroyed by the fire and temporary lights were installed. The walls and ceiling reflected virtually no light. The cameras used by Viametris iMS3D needed additional light in the smoke damaged areas, the temporary lights were not sufficient. Editing was needed for each photographic frame taken in the portion of the building damaged by the flame and heat to lighten the exposure. Even with the editing, the resulting images of the destruction are darker due to the conditions created by the fire.

Most of the interior of the modern side will need to be demolished due to the damage caused by the fire. With the web viewer provided by BIMRAY we can use the visual scan of the building to travel the building in a virtual tour, documenting everything as it was before demolition. This scan gives us a good look at the interior of the structure to make sure we do not miss anything taken during pack out of the contents or destroyed during demolition. While it is not a substitute for a physical count of all contents, it gives us a good look at what was in the building before pack out began (if you don't count it; it doesn't count).



2D floor plan of the 2nd floor with contents created with the LiDAR derived point cloud. Image created with Cloud Compare.

In the past, LiDAR scans of buildings have proved to be too expensive to be used universally. The rolling scan by Viametris is much more cost effective than the static tripod mounted scanners that must be moved and reset throughout a building. The Viametris technology makes the power of the laser scan economical and within reach of most projects.

Alan Sweeny II is the Technology and Maintenance Manager for the Library This was his first experience with LiDAR and said "When we look back on this event in the future it is truly mind-blowing to me that we will be able to see the condition of the library from the time of the fire in three dimensional space. This is not something I would have imagined was possible until learning about LiDAR technology through this project."

Currently, scanning a building prior to construction is not a common practice. Neither the library's Insurance Co., their construction consultant, nor the general contractor had ever worked with point cloud data. This project will be only the 2nd point cloud the architect has worked with. In time scanning a building prior to remodeling will become commonplace and manipulating point clouds second nature as more in the construction industry become comfortable working with BIM. The restoration of the Eckhart Public Library will be many of the projects contractors' first experience with the technology and without doubt not their last.

Chuck Knox is the owner of Knox Decorative Painting LLC (KDP). KDP is located in Fort Wayne, Indiana and has worked on many important projects in ne Indiana and nw Ohio. Chuck is also the owner of Knox Geological LLC and it is through his geology work that he started working with LiDAR correlating surface features and sub surface faults and fractures in drift covered areas.

A New Approach for Boresight Calibration of Low-Density LiDAR

Recent advances in LiDAR sensor technology has enabled low-cost laser scanners sufficiently light to be carried by low-cost drones. However, these sensors provide relatively low resolution making sensor alignment and boresight calibration difficult. Conventional techniques for LiDAR boresight calibration are based on the use of Ground Control Points (GCPs). Considering the challenges in identifying GCPs from low-density point clouds captured by these LiDAR sensors, such as that shown in **Figure 1**, we present a feature-based registration method that determines the boresight calibration parameters using control planes instead of individual points or any GCP's.

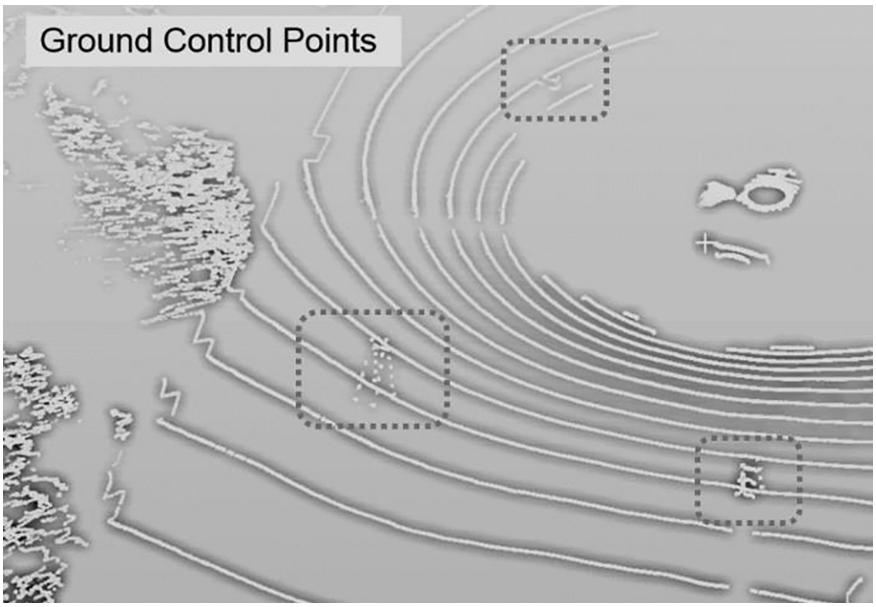


Figure 1: GCP Signature in Velodyne HDL-32E LiDAR Scanner 1

Mobile Mapping and Sensor Alignment

Mobile Mapping is the technique of acquiring accurate geospatial information of a scene using multiple sensors mounted on a mobile platform. A typical Mobile Mapping System (MMS) includes a Global Navigation Satellite System (GNSS) receiver, an Inertial Measurement Unit (IMU), and an active (LiDAR) or passive (camera) vision sensor. The accuracy of the MMS is dominated by the quality of the GPS/IMU trajectory and Sensor alignment. Sensor alignment is even more critical when the system is mounted on an UAV exposed to vibration effecting the alignment between IMU and LiDAR sensors. Additionally, due to limited field-of-view provided by light-weight MMS's, sensor alignment may need to be adjusted per project and changed based on objects of interest. Hence the alignment between IMU and camera or LiDAR sensors needs to be determined frequently, including after payload integration, project calibration, or scheduled calibration.

What Control Features Are Available?

Considering the limitations of identifying control points from low density scans, researchers have used higher level control features such as lines, planes or free-form surfaces that are common between the LiDAR point cloud datasets. **Figure 2** illustrate a control surface (dark gray) and an arbitrary surface (light gray). The arbitrary surface can be registered using control points, lines or surfaces that are visible in both data sets.

BY SUDHAGAR **NAGARAJAN** & SHAHRAM **MOAFIPOOR**

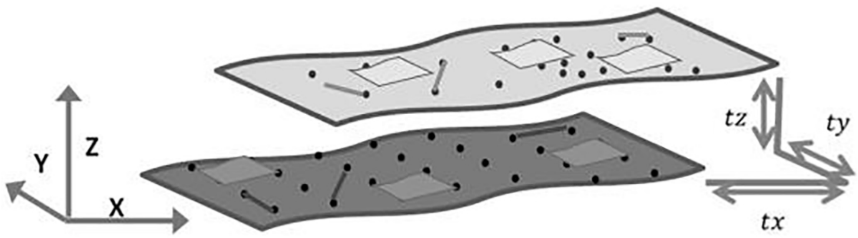


Figure 2: Illustration of registration by using control points, lines or planes

This paper demonstrates a method that takes all points constituting conjugate planes into the registration mathematical model in contrast to just a few sampled points. The proposed data-driven calibration method assumes that only mounting parameters constituting 3D rotation (boresight rotation angles) and 3D translation (boresight translation) exist between raw and registered point clouds. Hence one-to-one correspondence between mounting bias parameters and determined rigid body transformation parameters can be considered identical, as expressed in equation 1:

$$\acute{\boldsymbol{X}} = R(\omega, \varphi, \kappa)\boldsymbol{X} + \boldsymbol{T} + \boldsymbol{e} \quad \textbf{(1)}$$

where, $\boldsymbol{X}$ vector consists of coordinates of points in the control plane; $R(\omega, \varphi, \kappa)$ is the 3D rotation matrix formed with the boresight rotation angles; $\boldsymbol{T}$ is the boresight translation; $\boldsymbol{X}$ – is the vector that contains coordinates of points on the LiDAR plane, and $\boldsymbol{e}$ refers to random errors. The assumption of eliminating other systematic errors is justified as the proposed boresight calibration is performed in a laboratory without using GPS/IMU data and by keeping the MMS static for the duration of the calibration. In the case of the control-plane approach, the boresight calibration method will determine the alignment between IMU and LiDAR frame by minimizing the volume formed between low point density LiDAR surface with unknown boresight parameters and the control surface.

Volume Minimization Algorithm

The basic idea of the volume minimization method is to find transformation parameters that generate minimum volume between corresponding 3D planes in two coordinate systems. The volume computation between surfaces is not trivial. Hence we propose the use of 3D Delaunay triangulation to compute the volume between the corresponding surfaces. In this approach, 3D Delaunay triangulation is used to form a surface that represents the volume that needs to be minimized between conjugate planes. The total volume of all tetrahedra created through 3D Delaunay triangulation is given by Eq. (2) for n-tetrahedra. However, in the case of the boresight calibration problem, the LiDAR point cloud points will carry boresight angles and boresight translation as unknowns which should be determined by minimizing the volume between control and LiDAR surfaces. The control surface will be in IMU (body) frame and whereas LiDAR surface will be in a local LiDAR sensor frame. Though any free-form surface can be used in Volume Minimization, for simplicity planar patches are used:

$$V = \frac{1}{6}\sum_{i=1}^{n} \begin{vmatrix} X_1(i) & Y_1(i) & Z_1(i) & 1 \\ X_2(i) & Y_2(i) & Z_2(i) & 1 \\ X_3(i) & Y_3(i) & Z_3(i) & 1 \\ X_4(i) & Y_4(i) & Z_4(i) & 1 \end{vmatrix} \quad \textbf{(2)}$$

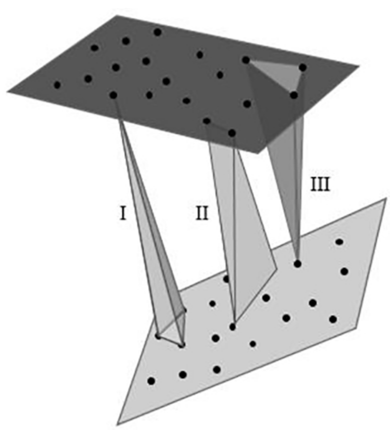


Figure 3: Three types (Type I, II and III) of tetrahedra that are possible between corresponding control (dark gray) and LiDAR (light gray) planes.

The proposed approach for determination of boresight alignment as 3D rigid body transformation is shown in the following steps:

1. Select 3 or more coplanar points on corresponding LiDAR and control point clouds
2. Establish the 3D Delaunay triangulation of both LiDAR plane and control plane points
3. Classify the generated tetrahedra into the following three types as illustrated in **Figure 3**
   - Type I—one point from control plane and three points from LiDAR plane
   - Type II—two points from control plane and two points from LiDAR plane
   - Type III—three points from control plane and one point from LiDAR plane

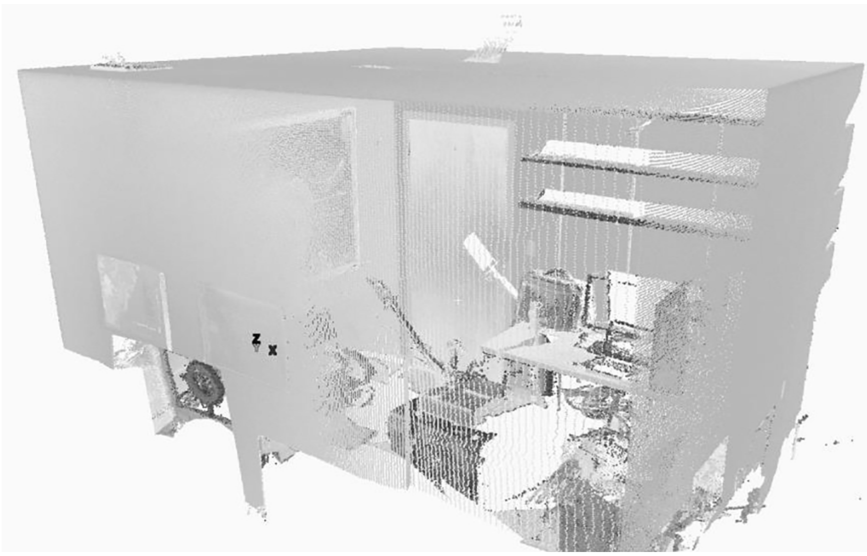


Figure 4: TLS point cloud with the MMS sensor in the middle of the room

4. Determine the rigid body transformation parameters that minimize the volume of each category tetrahedra. The volume between two planar surfaces from LiDAR and control data is the sum of volume of the tetrahedra that are formed only between them. In order to determine the 3D rigid-body transformation parameters that transforms the LiDAR points into control plane coordinate system or IMU frame, the volume equation needs to be written in terms of unknown transformation parameters. In accordance to the type I, II and III tetrahedra, coordinates in Eq. (2) can represent either coordinates of points in the control plane or coordinates of LiDAR plane points in the control coordinate frame denoted x_i,y_i,z_i. However, transformation between the LiDAR sensor frame and the control coordinate frame are unknown. Hence x_i,y_i,z_i need to be expressed in terms of a 3D rigid body transformation that also refers to boresight parameters as shown in Eq. (3):

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = R(\alpha,\beta,\gamma) \begin{bmatrix} x_i' \\ y_i' \\ z_i' \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} \quad \textbf{(3)}$$

In the equation above, x_i,y_i,z_i are the coordinates of the LiDAR point cloud in the control coordinate system. The coordinates of LiDAR points in sensor coordinates are given by x',y' and z'. Each observation equation in the form of Eq. (2) has to be expanded by plugging in Eq. (3). Then partial derivatives are taken with respect to unknown transformation parameters in terms of boresight angles denoted α, β *and* γ and boresight translationta denoted t_x , t_y and t_z for each tetrahedral types. The transformation parameters that minimize the volume of each tetrahedron is determined by volume minimization. Hence each tetrahedron volume equation is considered an observation equation for the least squares adjustment. As there are six unknown parameters, at least 6 tetrahedra that are formed between conjugate planes in LiDAR and control surface are needed. However, to avoid degeneracy, tetrahedra that represent three mutually perpendicular conjugate planes are required.

Lab Calibration and Experiential Results

We tested our approach by running the proposed algorithm in a closed room where multiple planar surfaces exist. The estimated calibration values were later used and evaluated on a UAV flight mapping MMS mission. Our MMS consisted of a Velodyne HDL 32E LiDAR and Geodetics' Geo-iNAV inertial navigation system. The MMS with installed LiDAR and GPS/IMU with its axis clearly visible were placed in the middle of the room such that the LiDAR sensor could capture most of the planes in the room without having to move the MMS. For ground truth, a 3D point cloud of the room was collected using an independent static Terrestrial Laser Scanner (TLS). By default, the static TLS collects data in its local coordinate system with its origin at the centroid of the scanning mirror after removing offsets. In order to transform the coordinate system of the TLS point cloud to the IMU coordinate system, first the plane containing X, Y axes are extracted from TLS data. Then IMU X, and Y axes that lies on the XY plane are digitized from the point cloud. The Z axis is perpendicular to XY plane and passes through the origin. By making these adjustments, TLS data is transformed to IMU frame and is used as control surface. After the TLS truth data collection, the MMS LiDAR sensor was used to collect 3D data of the room. **Figure 4** shows the 3D laser scan from TLS.

α	β	γ	t_x	t_y	t_z
-33.67°	33.81°	-127.46°	0.617 m	-0.012 m	0.552 m

Table 1: Boresight angles and lever-arm offsets computed using Volume Minimization algorithm

Similarly to the static TLS, by default the MMS LiDAR sensor data is collected in LiDAR sensor coordinates to which misalignment needs to be computed with respect to IMU frame. After the point cloud collection of both TLS and MMS LiDAR sensors and preliminary processing of TLS data, there will be two point clouds of the room, one in IMU frame and the other in LiDAR sensor frame. As discussed in earlier, in order to use the Volume Minimization algorithm, the LiDAR sensor should be placed such that at least 3 perpendicular planes are visible in order to avoid the volume minimization problem. Three such planes and two additional planes in the dataset are chosen from both the TLS and MMS LiDAR point clouds. Then volume between corresponding planes are determined using 3D Delaunay triangulation. The derived boresight parameters are shown in Table 1. The resulting estimated standard deviation per unit weight is 0.0361 cubic meters.

After boresight calibration in the lab-environment, the results were tested on a MMS UAV test flight. The flight plan was designed with multiple cross paths within the area of interest with the purpose of emphasizing the impact of uncertainty of boresight parameters on the georeferenced point clouds on the crossing paths. **Figure 5** shows the reconstructed point after applying the calibrated boresight parameters obtained with the presented approach. Once the boresight value determined from the results of the new approach is used, the point clouds are all aligned properly within the RMS of ±5cm.

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Dr. Shahram Moafipoor is the Director of Research & Development and the Senior Navigation Scientist at the Geodetics Inc., focusing on new sensor technologies, sensor-fusion architectures, application software, embedded firmware, and sensor interoperability in GPS and GPS-denied environments.

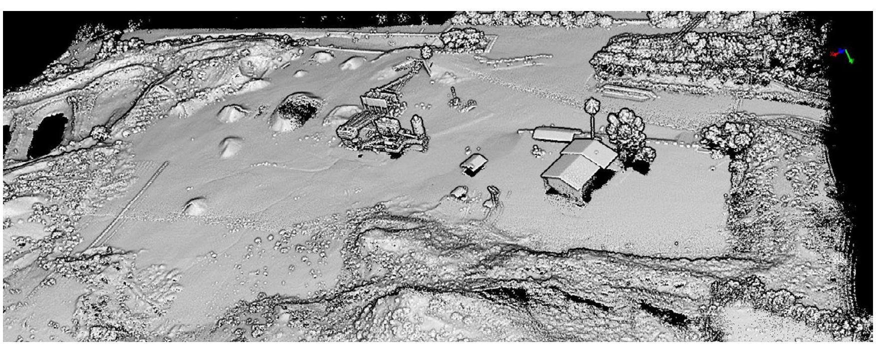

Figure 5: Point Cloud registration using calibrated boresight parameters with Geodetics' Geo-MMS

TED MORT

What I Didn't Expect to Learn at USIBD's 2017 Symposium

USIBD
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The hotel staff rushed around us preparing the sound, lights, and furniture, while putting all the final touches on the room for what would be the most attended Symposium yet.

As I and my fellow event committee members set up for the Symposium, I stood back and realized a newfound appreciation for where we've come as the Building Documentation industry. You see, three years ago we imagined a new kind of show, a show that would address and embrace subjects that would instigate change by talking about conflict, value and disruptive thinking… what's developing is something we couldn't expect.

In Dallas Texas, November 2017 we held the 3rd Annual USIBD Symposium in conjunction with the BIMForum, SEI, and AGC BuildCon. While the Symposium provides a great platform for Building Documentation industry stakeholders, the joint arrangement had quite a few unforeseen benefits for me.

First, it brought together a larger group of presenters and exhibitors who were excited to discuss how their products and services have the potential to bridge a series of gaps that exist between stakeholders and building lifecycle stages. Both presenters and exhibitors found an opportunity to speak with a diverse attendee group that represented owners, operators, builders and service providers. The mix of attendees also prompted conversions at the booths, which revolved around the perspectives of groups who exist on different sides of the gap they're working to bridge. This type of constructive and often passionate conversation wouldn't exist anywhere else.

Symposium venue, the room where it happened.

Second, I didn't realize how many of my clients would be in attendance! Several of my fellow USIBD members mentioned the same thing and where able to leverage the opportunity into dinner and networking following the day's events.

Third, and potentially the biggest surprise, came from the presentations I had the privilege to moderate during the day. The event was broken into 3 segments: a "Ted Talk" style series with multiple presenters, which concluded with a panel discussion where things got real. The next two segments were focused on the technology of Building Documentation, specifically the hardware and processes.

Materials boards created for the Scanner Shoot-Out comparisons.

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Graham, *continued from page 48*
perfect agreement, the residual would be zero. The residual comprises both a systematic shift (bias) and a random deviation. We correctly express the accuracy of a point cloud with respect to these independent check points by a metric called the Root Mean Square Error (RMSE). This is given by:

$$RMSE_Z = \sqrt{\frac{\sum_{i=1}^{N}(r_z)^2}{N}}$$

where
r_z is the vertical (z) residual
N is the number of test (check) points

We do this square root of the residuals squared trick because we do not want negative residuals canceling positive ones. There is an incredibly important but sometimes neglected relationship between bias, mean error and variance that needs to be considered when thinking about error analysis:

$$RMSE^2 = MSE = \bar{r}^2 + s_r^2$$

Where MSE is the Mean Square Error and:
$\bar{r}^2$ = the mean of the residuals, squared
s_r^2 = the square of the sample standard deviation (the variance) of the residuals

This says that, across all residuals we have measured, the Mean Squared Error is equal to the sum of the bias and the variance of the residuals. This is all fine and perfectly accurate. Where the problem comes in is the next step—it is often assumed that the distribution of the residuals is Normal. We have no reason to believe this; the Central Limit Theorem does not apply because we are not repeatedly measuring ensembles of the *same* thing!

Still, we are OK because the definition of variance (and its square root, the *standard deviation*) has nothing to do with the parent distribution of the data. It is only when we start to try to bracket errors based on multiples of the standard deviation that we get in to trouble—for example, saying that 95% of the data lie within 2 standard deviations of the mean. This is not true, in general, when speaking of residuals!

So finally, the rub. We want to remove the systematic error in our data (the point cloud) by adding (or subtracting) the mean of the residuals. But is this a valid operation? What is our confidence that the mean of the residuals truly represents the systematic error (bias) in our data?

Let me be a bit more concrete. Suppose we measure a bunch of check points and find a vertical mean error of 8.5 cm and a RMSE of 16.0 cm. This

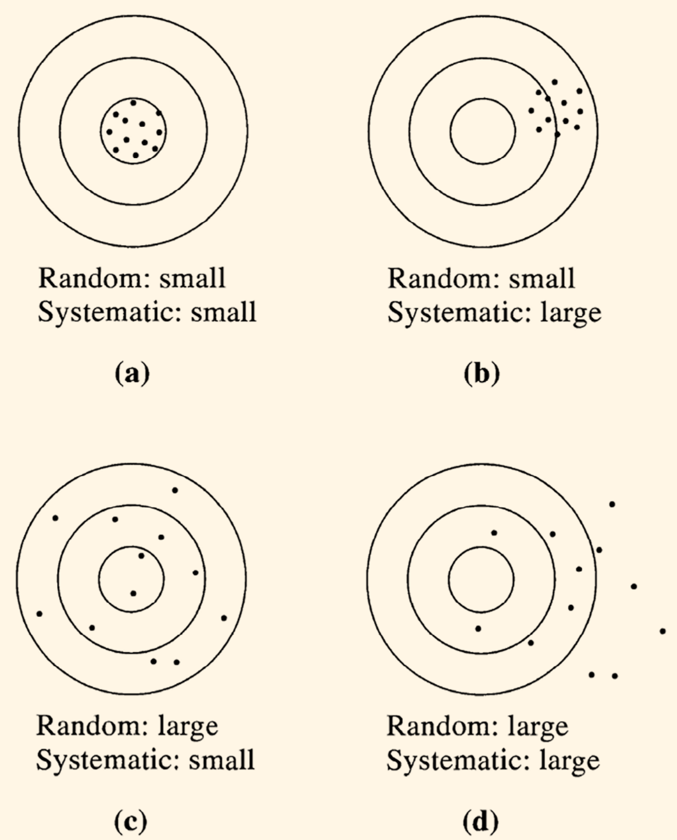

Figure 2: Mean and Deviation

tells us that the standard deviation of the set of samples is 13.6 cm (based on the formula above). Are we justified in removing the 8.5 cm of "bias" and recomputing the RMSE (which, if you are following all of this, would reduce to 13.6 cm)?

The answer is probably no. You can address this with a simple thought experiment. Imagine you start with a single check point and then keep adding check points. Suppose with one point you have a residual of 10 cm (with a single point, the standard deviation is undefined). Obviously you cannot remove this since you don't have any idea how much is bias (mean) and how much is noise. Suppose you add a second point with residual 10 cm. Now you start thinking, "wow, I have perfect data with a 10 cm bias!). But what if the residual is 5 cm? Do you then think "Oh, I have 7.5 cm of bias with some superimposed noise." You can see how this goes. You are forming qualitative ideas about the uncertainty of the mean but not quantitative. Most folks at this point latch on to the normal distribution and make assumptions about the randomness of the data based on a multiple of the standard deviation. This is generally wrong since, as we have already discovered, the residuals do not necessarily follow a Normal distribution.

So here I have left you with a problem. Fortunately, I have run out of room in this column to give the answer. Seriously though, we will continue this in a future column. In the meantime, not all is normal!

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

Mort, *continued from page 44*

Our first segment was an incredible cross section of industry perspectives from true thought leaders.

Everyone's presentation had to take place in under 20 minutes, and let me tell you, 20 minutes goes fast when it includes introduction and speaker swap! Even in the midst of tremendous time constraints the speakers were able to deliver their perspective on a specific and intertwined subject theme. When we entered the panel discussion these speakers had a chance to debate each other on differing opinions and conflicting positions. I personally found it refreshing to see so many passionate, intelligent game changers engage constructively on a platform like this… so often it seems that we become overly concerned with offending and ultimately have a vanilla conversation when it could be fierce and respectful.

After a short break we were treated to a first-of-kind head to head hardware comparison, the *Scanner Shootout*. More than 6 different laser scanners where used to document a variety of sample materials in a controlled environment. The results blew me away. I always believe, "Laser scanners are like hammers, one isn't better than another but they each have a purpose that they excel at and you can definitely pick the wrong hammer if you're not aware of the difference." I'm excited to see how far the USIBD takes this type of testing. Our goal is that we'll be able to make that information available soon to the public on USIBD's website.

The final segment didn't disappoint either. Several manufacturers and service providers agreed to measure one of the conference rooms in the venue, for the "Intent Defines Process: Use the Right Process for the Project" session. The parameters were based on an intentionally vague scoping document in order to compare the results.' They quantified the amount of time spent working, the deliverable product (2D floorplan) and the resulting area measurement. No surprise that we saw differences in the results, but I wouldn't have expected them to be so different. Ultimately, the moral of the story is that the quality and predictability of a product is often determined by the process in which we convey our goal (through the scope). This is the intention of USIBD's RFP document, available for purchase at USIBD's eStore.

Three reasons I wouldn't miss the next show:

1. So much info, so little time! Seriously, a full exhibit hall and over a dozen presenters in a day… bring an appetite for knowledge and be ready to disagree as much as you agree.
2. Networking. Period. Peers, competitors and clients all together and ready to engage.
3. Trajectory. Based on the year of year growth of this show, there's obviously something exciting going on. Get in on it now before it gets too big.

I'm looking forward to taking this show to the next level in 2018—you better be there!

Ted Mort is the Vice President and Operations Manager of Eco3d and provides direct oversight for the full scope of laser scanning and modeling on all projects.

RANDOM POINTS

LEWIS GRAHAM

What I mean is....

So the question this month relates to the so-called "Z Bump." When processing point clouds from both LIDAR systems and photogrammetric dense image matching (e.g. Structure from Motion, SfM), we are often faced with the question of vertical (and horizontal, for that matter) bias. It shows up as the mean of the residuals but is it truly a bias (a form of systematic error)? If so, can we safely remove it? I am going to outline the problem this month but I am not giving a definitive answer; I am still thinking about that aspect of the problem!

A quick illustration of how this problem appears in analytic software is shown in **Figure 1**. Here we see (in GeoCue's LP360 point cloud software) a check point (red symbol in the profile view) that appears above the point cloud. In other words, the point cloud appears depressed. The question is, can we shift the point cloud up by a constant amount to reduce or eliminate this shift?

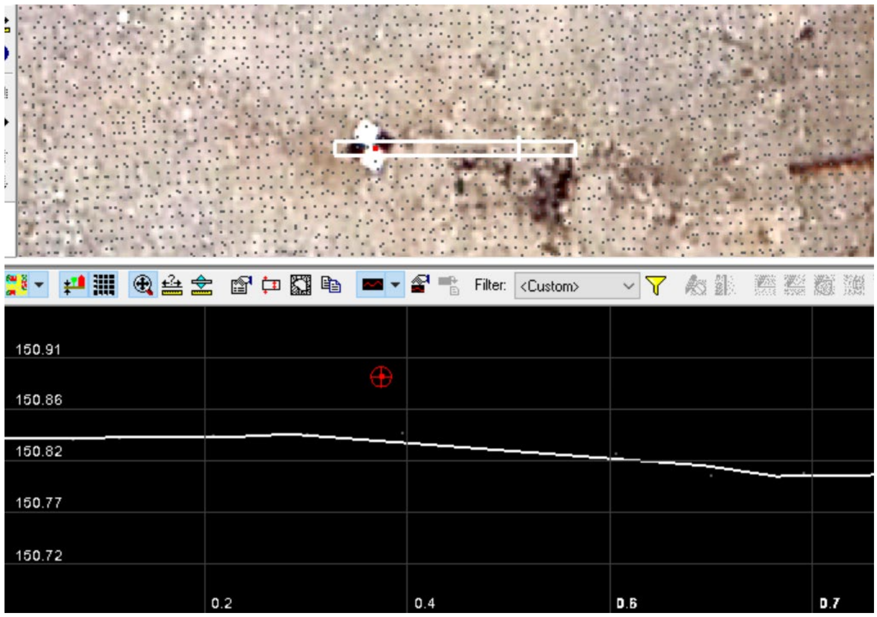

Figure 1: A point cloud that is lower than the true surface (depressed)

Let's meander around and give some thought to this very common processing problem. Consider the targets shown in **Figure 2** (from the book I cannot over recommend: "An Introduction to Error Analysis" by John R. Taylor). As pointed out by Taylor, the misleading thing about figures like this is that we can see whether or not we are achieving accuracy by virtue of the target rings. In the process of assessing point clouds, we do not have these rings. In other words, we do not know what "truth" is.

Our "targets" tend to be image identifiable ground check points that we survey in to measure *residuals*. Thus we have a good idea of accuracy at these check points but nowhere in between. For those from the signal processing community, you will immediately recognize that when we assess point cloud accuracy, we are very seriously violating the Nyquist sampling criteria!

I call the measure of how well a point cloud fits the true object space *conformance*. As far as I know, very little has been published to date on conformance or how it can be measured. More on that in a future article. A ubiquitous problem in the mapping industry is that we tend to misapply Gaussian ("Normal") statistics. One of the most important theorems in all of statistics is the Central Limit Theorem (CLT). This theorem basically states that metrics (such as the mean) from ensembles of independent random samples tend toward a Normal distribution regardless of the true distribution from which the samples are drawn. The CLT is often misapplied when analyzing error.

When we test the vertical accuracy of a point cloud, we do so by measuring the vertical distance from an independent check point to the point cloud. We call this measurement a *residual*. If we had

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