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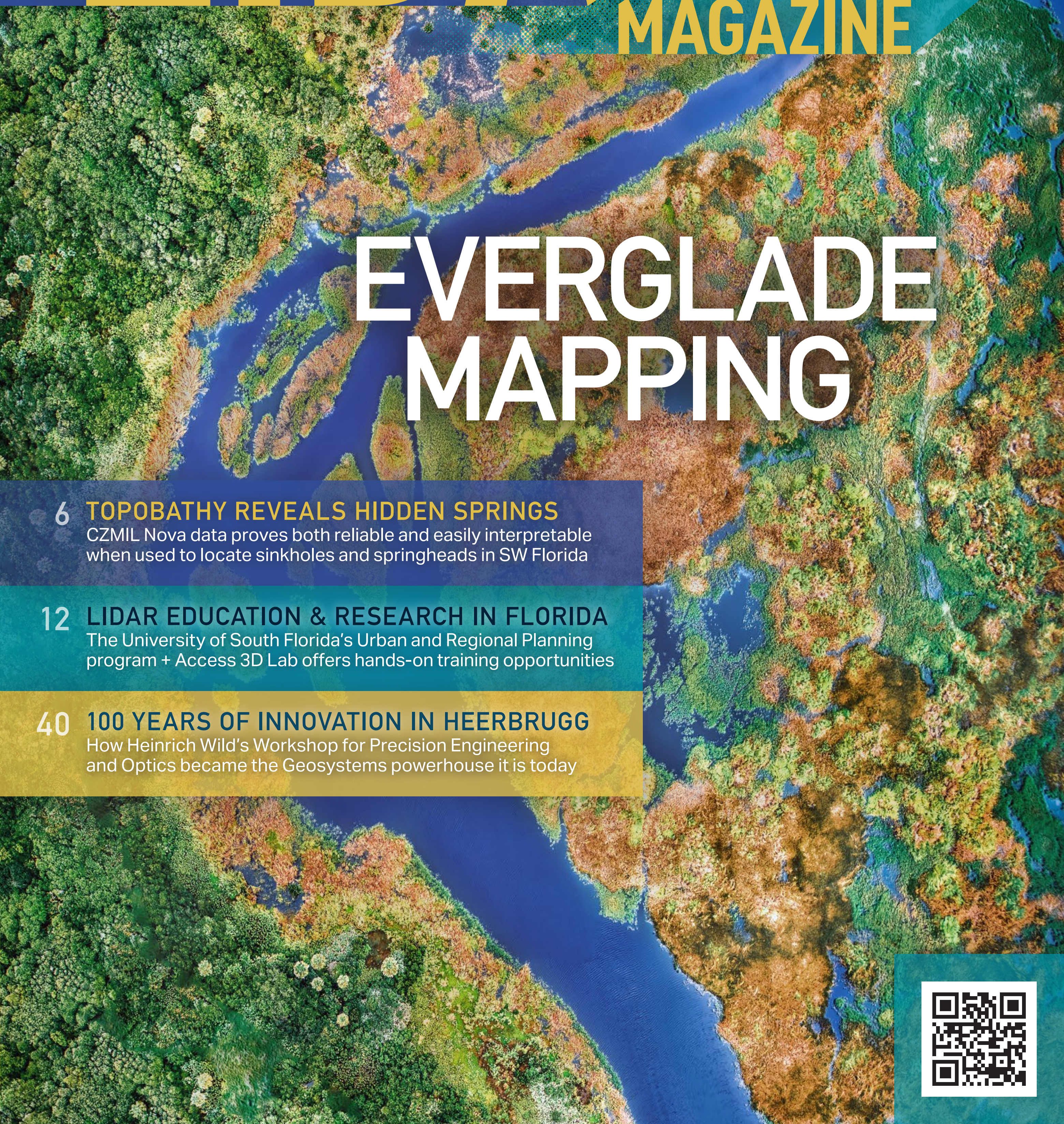
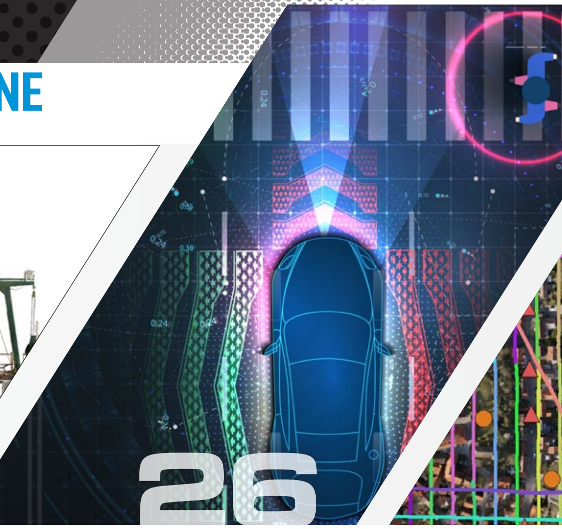


EVERGLADE MAPPING

LIDAR MAGAZINE



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ON THE COVER

Aerial View of Guana River Wildlife Preserve
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FROM THE EDITOR

DR. A. STEWART WALKER

Quarterly Forecast

This issue marks our shift to four print issues per year—to bring you more substantial magazines, with more articles in each. This issue's content begins with an important piece by three authors from the University of Stuttgart, establishing that UAV collection of both imagery and lidar, with suitable ground control and careful processing, can yield remarkable accuracies—better than 1 cm. This opens up dramatic possibilities for monitoring structures, checking for subsidence etc. Indeed, establishing ground control of sufficient accuracy to tie down such UAV-derived networks is a challenge in its own right! *LIDAR Magazine* is not a peer-reviewed journals, so when renowned names from universities publish with us we are honored and delighted.

Readers know Leica Geosystems, part of Hexagon, and its lidar units have been described in these pages on many occasions. The evolution of Leica Geosystems is complex; suffice it to say that it began with a company founded in Heerbrugg, Switzerland by the brilliant designer Dr. Heinrich Wild. Some of its products, such as the T2 theodolite and the A8 and B8 stereoplotters, became workhorses throughout our industry. An exciting series of events planned to mark Wild's centenary in 2021 was disrupted by the pandemic. We are fortunate, therefore, to have secured an article written by Leica Geosystems physicist Dr. Eugen Voit, who retired in 2018 and has become deeply involved in investigating and recording the history of the company. Eugen provides a concise, engaging perspective and many readers will want to dig deeper as a result!

At the component rather than company level, an article by Dr. John Wilson of BrightView Technologies describes his company's approach to the design and manufacture of technology for the shaping of laser beams. This matters for automotive applications, not only looking at the situation on the road ahead and around the car, but also monitoring what's going on inside, for example checking for driver fatigue.

Regular contributor Dr. Alvan Karlin of Dewberry has been busy and we have two of his articles. The first is a synopsis of the 13th Lidar Workshop run by the University of Florida and the Florida Region of ASPRS. The second shows how a test flight of Dewberry's CZMIL Nova sensor pinpointed springs and feeds that form part of the intricate network supplying Florida's critical wetlands. Major springs, of course, have already been mapped, but the remoteness and dense vegetation have precluded the recording of many less significant karst features until now.

The University of South Florida (USF) has been a frequent contributor to the lidar workshops. Two of its academics, Laura Harrison and Steven Fernandez, have submitted an article about the lidar education available there. It's extensive and large numbers of students

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learn not only how to use hardware and software but also how to apply them to interesting, practical projects.

Harrison and Fernandez begin with the statement, "Demand for employees with education and training in advanced geospatial technologies is at an all-time high…" They introduce the USF response by explaining that two units within the university are working together, "… to create the nation's most advanced hands-on training opportunities in lidar and geospatial technologies." It's very strange, therefore, that, shortly before I wrote these words, I received a disturbing e-mail from Jon Mills, professor of geomatic engineering at the University of Newcastle in the north of England. Jon has published extensively on photogrammetry and lidar and is well known in EuroSDR and ISPRS circles. His graduates are employed in the geospatial industry around the globe. He had the unpleasant task of informing his department's mailing list that the School of Engineering is closing down two undergraduate programs in geospatial engineering—BEng Geospatial Surveying and Mapping and BSc Geographic Information Science—owing primarily to low levels of recruitment of students. There is no criticism of the product, i.e. the geospatial education that has been provided for many years, or of the abilities of the graduates from these programs. There are simply too few students for the programs to be viable. If you want to write to the University's vice chancellor, I can share Jon's e-mail with you. It appears that Newcastle and USF are moving in completely opposite directions, yet the Newcastle experience perhaps has a parallel in the US: the average age of professional land surveyors is high and is not decreasing, due to the small numbers entering the profession. Why are we unable to attract young people to our geospatial world with its glittering technologies, challenging projects and societally beneficial results?

Last in this issue is a review of the second edition of *High Resolution Optical Satellite Imagery*, a book by four famous authors that's worth a read even by lidar folk, because earth observation from satellites is so pervasive—every day we see images of war in Ukraine, devastation of the Amazonian rain forest, etc., so it's worth knowing more about how they are acquired and used. The book comes from Whittles Publishing, a small operation located in Dunbeath, a little village on Scotland's northeast coast. Whittles has published numerous well known geospatial texts, so I became fascinated that a publishing house in such a remote location should figure so prominently. On a recent vacation in Scotland, I passed through Dunbeath while following the North Coast 500 route which the Scots have marketed so successfully, so I contacted Keith Whittles in advance and we met for a couple of hours. A charming Englishman with BSc and PhD degrees in geology, he was offered an assistant professorship in Scotland, but instead joined the publisher Blackie in Glasgow. His career was successful, yet he decided to set up on his own 37 years ago and moved north. His premises are a converted mill. I had assumed that he would have a tiny office and do everything remotely, but, no, there are five employees, who work partly in the office and partly from home. Typesetting and printing are contracted out, but there's a lot going on in Dunbeath.

My Scottish trip ended in Edinburgh. I met up with Dr. Roger Kirby, who retired some years ago from the Department of Geography, University of Edinburgh, where he had led courses in geomatics and glacial geomorphology for decades. Roger lives in Haddington, close to an area of archaeological significance. Archaeologists are curious whether faint circular features in public lidar data could indicate the site of a motte-and-bailey castle. If the suspicion were confirmed, funding would be sought for UAV-lidar data and perhaps even an investigation with ground-penetrating radar. Sadly, there are no resources even to have the point cloud examined.

My reading on vacation was limited, but I enjoyed positive pieces from the UK press about autonomous vehicles[1] and artificial intelligence[2]. The former ends with the words, "… buckle up for the driverless revolution, but expect a few potholes on the way." On returning home, my local newspaper had a long piece about potholes[3], a ubiquitous plague in San Diego. The city has hired Fugro to conduct a detailed survey. The article is not explicit, but I suspect Fugro will be using one or more of its ARAN 9000[4] mobile mapping systems with special lasers to monitor surface roughness. A survey isn't a cure, but it's a good first step…

A. Stewart Walker // Managing Editor

1 Yeomans, J., 2023. My day in a robocar, *The Sunday Times*, 2 April 2023, Business p6.
2 Parsons, K., 2023. AI can power productivity beyond our dreams, *The Sunday Times*, 2 April 2023, Business p6.
3 Garrick, D., 2023. Where are San Diego's worst potholes? A laser-equipped van is roaming 2,800 miles of city streets to find out, *Poway News Chieftain*, 70(47): A4, 13 April 2023.
4 fugro.com/our-services/asset-integrity/roadware/equipment-and-software

Topobathymetric Lidar Reveals Hidden Springs in Florida

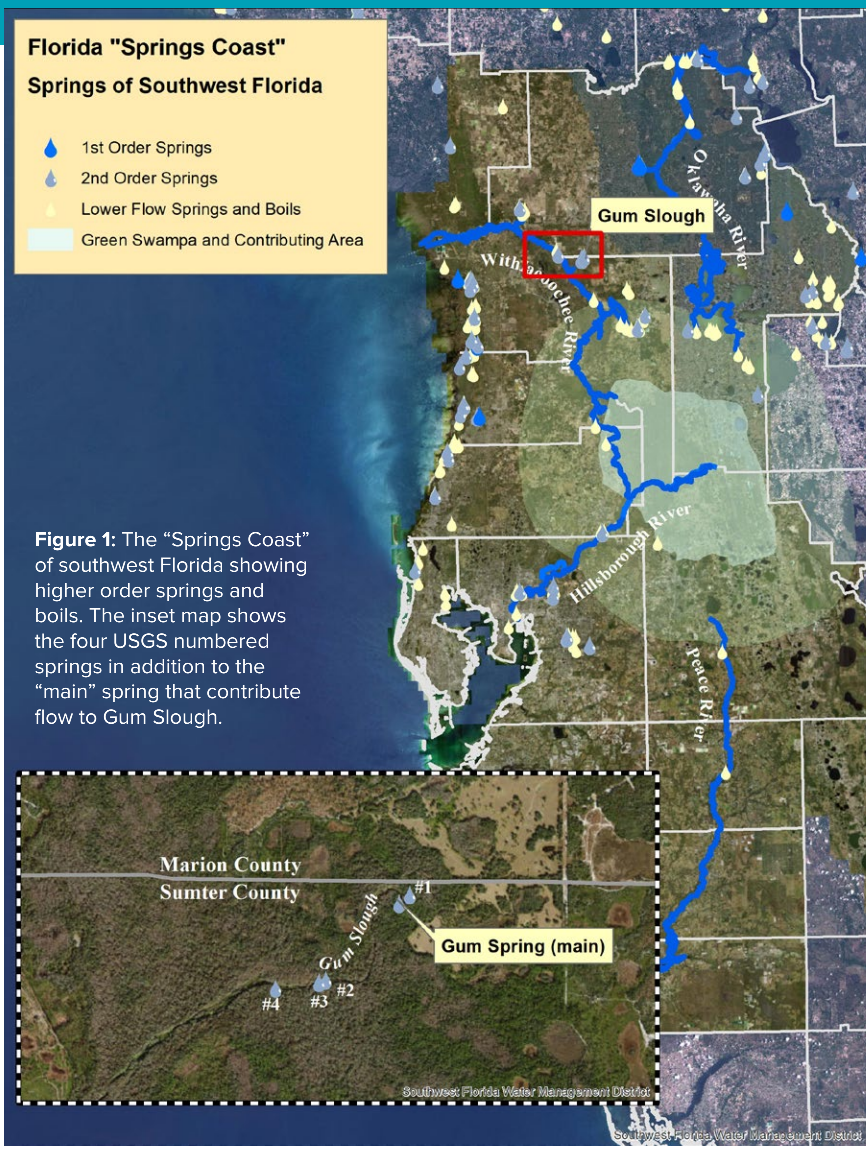

Figure 1: The "Springs Coast" of southwest Florida showing higher order springs and boils. The inset map shows the four USGS numbered springs in addition to the "main" spring that contribute flow to Gum Slough.

Gum Slough's hydrology and karst features discovered in CZMIL Nova data

We would always tease hydrogeologist colleagues that in southwest Florida there are probably 1000 types of rocks, 999 of which are limestone, because, whenever geologists would drill a well into the earth, they identified hundreds of differently named rocks in the cores, but these are all just names for different limestones. This limestone, dissolved away over the past several thousand years, resulted in the karst geology that gives rise to sinkholes and springs throughout the state. This springshed system also forms the hydrological heart of the peninsula of Florida, the Green Swamp. Four major rivers incise the peninsula of Florida: the Hillsborough, Ocklawaha, Peace and Withlacoochee. All have their headwaters in and around the Green Swamp.

BY ALVAN **KARLIN,** DANIELLE **ROGERS** AND EMILY **KLIPP**

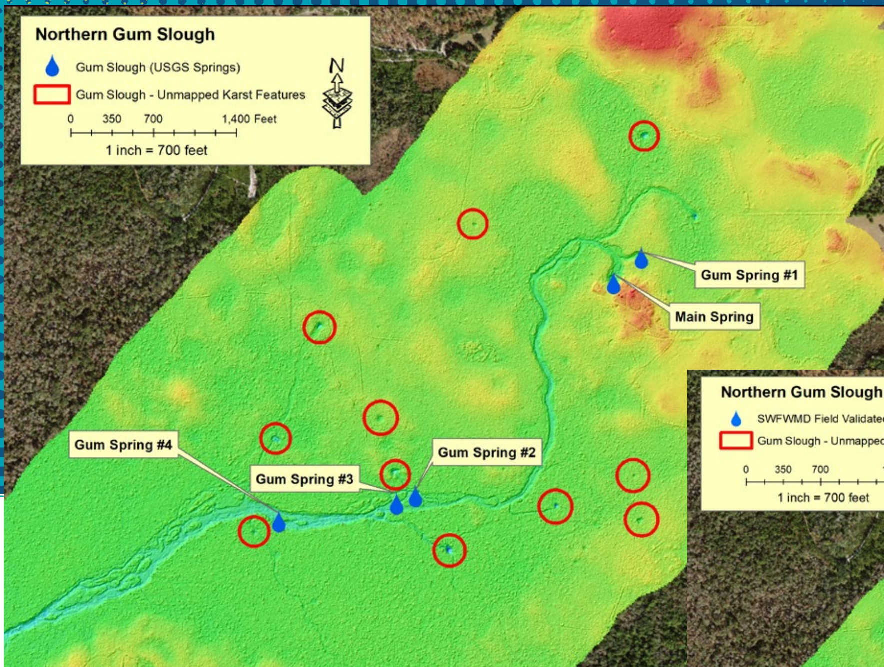

Figure 2: Northern portion of Gum Slough showing the five feeds contributing to 2nd magnitude springs mapped by USGS. The red circles are areas of at least 11 new, potential karst features, sinks or springs, which were revealed in the CZMIL topobathymetric lidar data. In addition to the unmapped karst features, the CZMIL data revealed the braided nature of the slough.

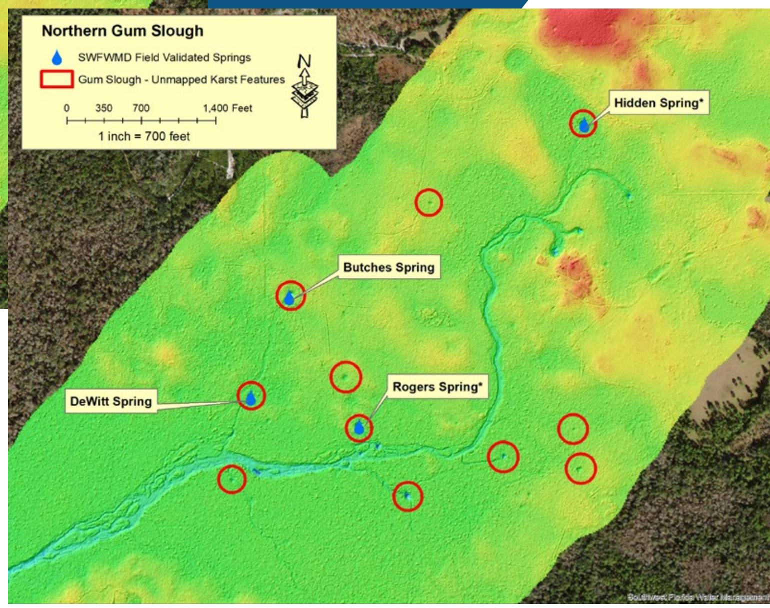

Figure 3: Northern Gum Slough showing the locations of four SWFWMD field-verified newly discovered springheads. The asterisk (*) by the spring name refers to the ground-level photographs in **Figure 4**.

The Florida Geological Survey (FGS) has been mapping the extensive distribution of springs in Florida for over 25 years and, in 2003, published *Special Publication No 52,—Florida Spring Classification System and Spring Glossary*[1] and a map of the first order springsheds[2]. Since then, the US Geological Survey (USGS) has recognized 27 1^{st} magnitude (≥100 ft^3/s average flow) springs in Florida, seven of which are found in the region surrounding the Green Swamp[3]. There are many more 2^{nd} and 3^{rd} magnitude springs. These smaller springs, with lower average flow, are often difficult to locate either because they occur in remote, difficult to reach, densely forested bottomlands, or they emerge as underwater boils in bays and shallow coastal waters. Although locating underwater boils was not the purpose, a 2015 topobathymetric lidar survey using a Coastal Zone Mapping and Imaging Lidar (CZMIL) topobathymetric lidar system in Kings Bay/Crystal River on the Springs Coast revealed the location of several likely unknown 2^{nd} and 3^{rd} order springs[4]. Thus, we suspected that additional topobathymetric surveys of inland Springs Coast waterways would similarly reveal previously unknown springs.

In the winter of 2021, when Dewberry acquired a Teledyne Geospatial CZMIL Nova topobathymetric lidar sensor, several test flights were conducted in the Tampa Bay area. In part as a proof-of-concept demonstration and in part to assist the Southwest Florida Water Management District (SWFWMD), Dewberry mapped a spring run, Gum Slough, on the Sumter/Marion County border (**Figure 1**).

Gum Slough runs for approximately 7.4 km (about 4.6 miles) from the main springhead to the confluence with the

1 lake.wateratlas.usf.edu/upload/documents/SP_52-Fla-Springs-Classification-Glossary-2003.pdf
2 aquadocs.org/handle/1834/18414
3 pubs.usgs.gov/fs/1995/0151/report.pdf

4 Kalvin, A., A. Nayegandhi and J.F. Owens, 2017. Topo-bathymetric lidar on the Springs Coast of Florida, *LIDAR Magazine*, 7(4): 36-43, June 2017.

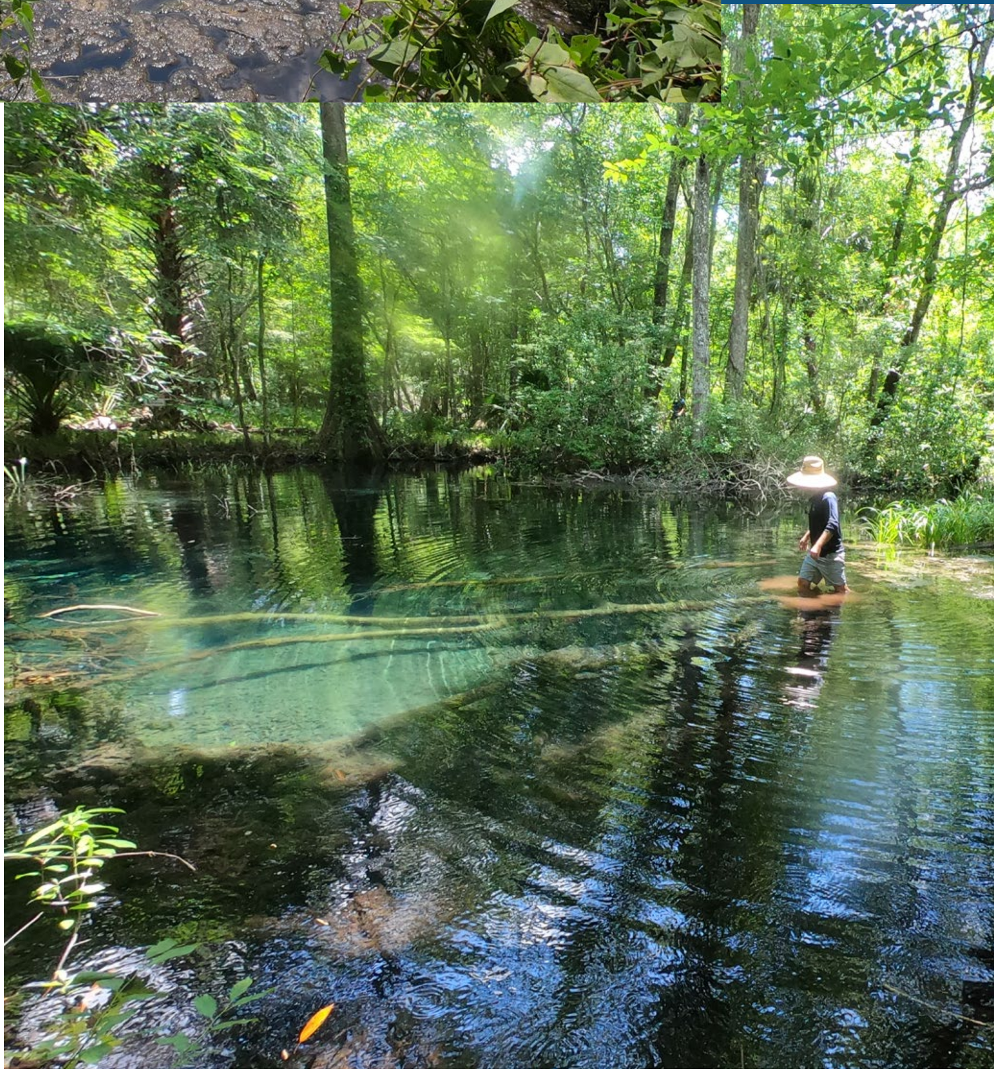

Figure 4: Hidden Springs (top) and Rogers Spring (bottom). Photographs from the SWFWMD field verification visit on 17 May 2022.

Withlacoochee River, through dense bottomland vegetation. The only access to the run is near the primary springhead, through gated, privately owned property. The nearest county road is over 2.5 km away! From the FGS and USGS mapping surveys, five feeds contributing to 2nd order springs, the main springhead and four auxiliary springs (**Figure 2**), were known to contribute to the flow in the slough. Indeed, USGS installed a water-level gauge at the junction of Gum Slough and the channel of the Withlacoochee River[5], which is monitored by SWFWMD.

Flight mission and data processing

Dewberry flew a Teledyne Geospatial CZMIL Nova sensor over the Gum Slough area of interest (AOI) on 5

5 waterdata.usgs.gov/fl/nwis/uv?site_no=02312764

Class	Definition
1	Unclassified, used for all other features that do not fit into the ASPRS classes 2, 7, 9, 17, 18 and 20; may include vegetation, buildings, etc.
2	Bare-earth ground (terrestrial)
7	Low noise
18	High noise
40	Bathymetric point (submerged ground)
41	Water surface
42	Synthetic/derived water surface, used for computing refraction surface
45	Water column

Table 1: ASPRS classification scheme with definitions used for Gum Slough topobathymetric lidar.

February 2021. The AOI consisted of 14 5000' x 5000' tiles referenced to the Florida Statewide State Plane West Tiling System[6], completely surveying approximately 7.5 km (4.6 linear miles) of the spring run. The mission was designed to meet or exceed the density (≥2.0 ppsm) and accuracy requirements (10 cm $RMSe_Z$) for National Coastal Mapping Strategy 1.0 QL2b standard[7]. The point density and accuracy, 5 ppsm, and 3.87 cm $RMSe_Z$ (on non-vegetated terrain) respectively, exceeded the specification.

Bathymetric lidar data must have a refraction correction applied, which adjusts the horizontal and vertical (depth) positions of each data point by accounting for the change in direction and speed of light as the laser pulse enters and travels through water. The refraction correction was performed by Dewberry using the Dewberry Lidar Processor (DLP) tool.

6 floridarevenue.com/property/Pages/Cofficial_GIS.aspx

7 iocm.noaa.gov/reports/IWG-OCM-Natl-Coastal-Mapping-Strat-DRAFT-PUBLIC-COMMENT-4.29.16.pdf

The refraction tool uses a modeled water surface and mission-smoothed best estimate of trajectory (SBET) data to correct the ranging and horizontal placement of all green (i.e. collected with 532 nm laser) lidar points initially classified as water column. The initial water column classification is based on breakline placement. The refraction tool creates a new output data file and does not modify the input files.

After data calibration and refraction, Dewberry used CARIS™ and TerraScan™ software for processing. The raw point clouds were imported into CARIS for conversion to LAS format and output with an initial classification schema based on stored sensor data. The LAS files were tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan, which classified obvious low outliers in the dataset to class 7 and high outliers to class 18. Points along flight line edges that were geometrically unusable were flagged as overlap and allocated to a separate class so that they would be excluded from the initial ground algorithm. After points that could negatively affect the ground were removed from class 1, the ground layer was extracted from this remaining point cloud using an iterative surface model.

Following the initial automated ground routine, each tile was imported into TerraScan and a surface model created. Dewberry analysts visually reviewed the topobathymetric surface model and corrected errors in the ground classification such as vegetation, buildings, bridges, and grounded water column or surfaces that were in ground classes following the initial processing.

Analysts also looked for features that were present in the point cloud but not reflected in the ground model, including obstacles to marine navigation. The final point-cloud classification is shown in **Table 1**.

All data delivered to SWFWMD were formatted to ASPRS LAS 1.4 Point Data Record Format 6, referenced to the Florida State Plane West, NAD 1983/2011, NAVD88 (Geoid 2018) in US feet.

Field verification

On 17 May 2022, a SWFWMD team deployed, over land on foot, to field-verify the locations of several of the karst features revealed by the CZMIL data. They confirmed the springhead locations for four springs later that summer[8]. The team visited four of the 11 potential new springhead sites (**Figure 3**). The team verified and inspected the four sites, identified the spring outlet (on subsequent visits) and recorded a GNSS position for each new spring. The four newly discovered springheads now have SWFWMD-recorded names of (from north to south) Hidden Spring (**Figure 4** top), Butches Spring, DeWitt Spring and Rogers Spring (**Figure 4** bottom).

Conclusions

Natural springs are major contributors to flow in the waterways of Florida. The water management districts must be able to identify those potential flow inputs and parameters in natural systems, so accurately mapping the springs is paramount. In dense vegetation, which precludes aerial photography as a tool to map those springs, other methods need to be employed.

The CZMIL Nova topobathymetric sensor was used to map the floodplain and the course of Gum Slough. While the major springheads were known and mapped by FGS and USGS, the CZMIL Nova survey revealed the locations of at least 11 previously unidentified “karst features” in an economical survey. Following SWFWMD field verification, it appears that topobathymetric lidar data is reliable and easily interpretable and can be used to locate additional karst features, such as sinkholes and springheads, through the dense vegetation found in the swamps, floodplains and wetlands of Florida.

Acknowledgements

We would like to acknowledge all of the support that this project received from both the SWFWMD Bureau of Natural Systems and Restoration and the bathymetric lidar team at Dewberry. This project originated as a test flight that developed into a fully calibrated survey. The SWFWMD Environmental Flows and Levels section sweltered through the summer heat to field-verify the locations of potential springheads as mapped by the CZMIL Nova.

8 m.youtube.com/watch?v=b9PXOXQzs-4

Alvan “Al” Karlin, Ph.D, CMS-l, GISP is a senior geospatial scientist at Dewberry, formerly from the Southwest Water Management District (SWFWMD). While at SWFWMD he managed all of the remote sensing and lidar-related projects in mapping and GIS. With Dewberry, he serves as a consultant on Florida-related lidar and imagery projects, as well as general GIS-related projects. He has a Ph.D in computational theoretical genetics from Miami University in Ohio. He is a Director on the Board of the Florida Region of ASPRS, an ASPRS Certified Mapping Scientist—Lidar, and a GIS Certification Institute Professional.

Danielle Rogers, PWS, PMP is an Environmental Project Manager in the Natural Systems and Restoration Bureau at SWFWMD. She has worked for the District for 17 years and is a professional wetland scientist and project management professional. Prior to joining the District, she worked as an environmental specialist for the Florida Department of Environmental Protection and as a project technician in the private sector. Her experience is in coastal and lotic ecosystems, springs ecology, geographical information systems spatial analysis, mobile mapping technology and geospatial model development. She earned a master’s degree in Marine Affairs from the University of Miami, Rosenstiel School of Marine and Atmospheric Science. Her program focused heavily on understanding cumulative and secondary impacts in ecosystems, coastal law and translating scientific information into policy.

Emily Klipp is a project manager with Dewberry and has more than 15 years of experience working with topographic and topobathymetric lidar data. She specializes in geospatial project planning and management, QA/QC of topographic and bathymetric data, vertical and horizontal accuracy assessments, and creation of a variety of digital mapping products using various software platforms. Emily has led topobathymetric and topographic lidar projects for USGS, NOAA, USFWS, and SWFWMD. Emily is a member of ASPRS and has presented reports at several ASPRS annual meetings and Geo Week conferences, as well as other professional meeting venues. From 2007 to 2014, she authored more than 35 data series and reports for USGS and helped manage operations and data production of the NASA/USGS EAARL sensor for the USGS Coastal Program.


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Figure 1: USF graduate students in the Master of Urban and Regional Planning program executing a scan plan at Tampa's historic Union Station, a site on the National Register of Historic Places.

Innovations in Lidar Education and Research at the University of South Florida

BY LAURA K. HARRISON AND STEVEN FERNANDEZ

Demand for employees with education and training in advanced geospatial technologies is at an all-time high, because of the rapid growth of the lidar industry in recent years. To meet this demand, the University of South Florida's (USF) Urban and Regional Planning program and Access 3D Lab have partnered to create the nation's most advanced hands-on training opportunities in lidar and geospatial technologies (**Figure 1**).

As one of the ten largest research universities in the country, USF is committed to innovation, and has recently made strategic investments in terrestrial, mobile, and aerial lidar.

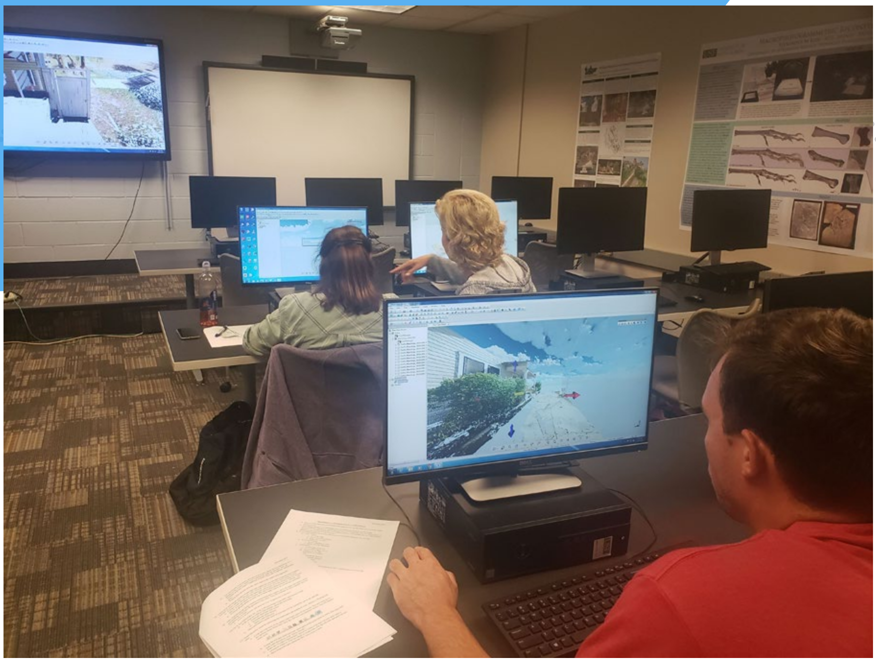


Figure 2: The 24-seat digital learning classroom at USF's Access 3D Lab.

Figure 3: These students earned an @Access3D Gold Badge by completing independent lidar scanning and processing projects over the course of three intensive weeks.

These investments support our training programs and propel research in urban planning, cultural heritage preservation, tourism, and destination management. Our programs involve undergraduate and graduate students in dynamic geospatial research, with projects taking place year-round in the United States and Europe (with a focus in Florida). As a result, each year we produce a cohort of highly-trained college graduates with experience capturing and processing lidar data in authentic, real-world scenarios, who are ready for the workforce.

Lidar education

Lidar education and training opportunities at USF are diverse. A new graduate certificate in Smart City Technology is launching in Fall 2023. This covers GIS, lidar analysis, 3D modeling, programming, and terrestrial and mobile lidar. Courses in building information modeling (BIM) will be added to the curriculum for 2024. In addition, Access 3D Lab offers advanced training workshops in geomatics each May, which provide firsthand experience working with lidar in the field and in the lab. A key focus of all educational programs is hands-on experience tailored to career advancement. Classes are held in our state-of-the-art classroom, equipped with powerful Alienware Aurora R12 computers with 64GB of RAM, NVIDIA GeForce RTX 3080 graphics cards, and 1TB solid-state drives (**Figure 2**).

Core courses in the new Graduate Certificate in Smart City Technology include: GIS for urban and regional planners; urban spatial analysis; and lidar and 3D applications of GIS. Electives include: terrestrial lidar field methods; digital design; programming for GIS; water resources applications of GIS; and public information management.

Workshop topics to date have been: Ybor City lidar: spatial and visual analysis of a National Historic Landmark District (2019); applied heritage and sustainability research (2019); sustainable tourism interpretation and citizen science (2021); cultural heritage and climate change geomatics (2021); geomatics for heritage, tourism, and sustainability planning (2022).

Access 3D Lab's highest certification of applied technology skills is the @Access3D Gold Badge (**Figure 3**).

Lidar research

USF's lidar education and training programs support our ongoing fieldwork projects: students serve as crew members during data acquisition and help produce project deliverables, GIS maps, and project reports back in the lab (**Figure 4**). Some of our current research projects with an urban planning focus include using lidar to analyze King Tide flooding in South Florida and the Tampa Bay region; storm surge modeling for seven counties' hurricane shelters; local GIS analysis and mapping of food sustainability in Tampa Bay for the Homegrown Hillsborough Food System Program; and developing a web-map application for a grant from the Florida Department of Early Learning to evaluate the Early Learning Coalitions' capacity to support infant and early childhood mental health. These projects are funded through external grants.

In addition, the USF training programs are using lidar extensively in the realm of cultural heritage preservation. For example, a student crew planned and carried out a terrestrial lidar scan of a historic lighthouse on Egmont Key, Florida, creating a durable record of the state of preservation and providing virtual access to the lighthouse's interior, which is closed to visitors. Another student crew completed a terrestrial lidar scan of a historic Spanish-American-War fort, and then simulated the effects of sea-level rise on the structure using NOAA data in GIS (**Figure 5**). Yet another student crew scanned four murals in downtown Clearwater, Florida

> "Demand for employees with education and training in advanced geospatial technologies is at an all-time high."

Figure 4: Orthophoto of a lidar scan of the R/V Weatherbird II, a research vessel owned by the Florida Institute of Oceanography. The scan data was captured with Faro Focus scanners over the course of four days and processed in Faro Scene.

Figure 5: A team of students in the Cultural Heritage and Climate Change Geomatics workshop setting up the scan profile of a Faro Focus.

with terrestrial lidar and used measurements from those scans to program an augmented-reality app called ARTours Clearwater (**Figure 6**). The lidar-derived measurements ensure accurate tracking and image recognition within the app, allowing visitors to experience interactive digital stories while walking through a downtown arts district.

Research faculty

USF's lidar training and research projects are spearheaded by Steven Fernandez, MA, CCM, GISP and Laura K. Harrison, PhD, MA, RPA, who collaborate widely with USF faculty colleagues as well as partners in government agencies, Native American tribes, the nonprofit sector, associations, and community groups.

Steven Fernandez is a Research Assistant Professor in the Master of Urban and Regional Planning (MURP) program at USF. His expertise is in geospatial technologies, including GIS, UAS, lidar mapping and analysis. Steven has 22 years of experience in the private sector, working on site suitability and location analysis for commercial real estate. Those projects were completed for over 250 municipalities in 20 states, 50 of which required fieldwork data collection. His first experience with lidar was in 2001, modeling barrier-island erosion for the south shore of Long Island, New York. In 2010, he joined a research center at USF, where he was a GIS project manager for terrestrial and aerial lidar projects. The lidar projects were conducted throughout the eastern United States, US Virgin Islands, Hawaii, Europe, Mexico, and Guatemala. In 2018, he joined the MURP program, where he developed four graduate courses that focus on urban planning and lidar applications of GIS. These

Figure 6: A lidar scanner on a hydraulic lift in Clearwater. A team of students scanned this mural and three others for the ARTours Clearwater augmented-reality walking tour.

courses are the basis of the Graduate Certificate in Smart City Technology.

Dr. Laura Harrison is a Research Assistant Professor and Director of USF's Access 3D Lab. Her research uses digital tools such as lidar, photogrammetry, and virtual and augmented reality to preserve heritage sites, expand public access and understanding of culture, involve the public with archaeology, and develop sustainable and resilient cultural heritage tourism. She has experience working with lidar in Spain, France, Italy, Turkey, and Serbia as well as multiple locations throughout the United States. Before she became involved with digital technologies such as lidar and 3D scanning, Laura worked on archaeological research projects in Greece, Turkey and New York. Her current research blends anthropological perspectives with advanced technologies to address real-world problems such as climate change, urban blight, endangered heritage, and invisible histories.

Get connected

To stay up to date with the latest lidar training and education opportunities, and learn about our current research projects, visit usf.edu/arts-sciences/departments/public-affairs/murp and usf.edu/arts-sciences/labs/access3d. Our interactive web viewer (**Figure 7**) is available at the USF Urban and Regional Planning GeoHub: usf-urban-planning-usfurp.hub.arcgis.com. Also follow @MURP on LinkedIn and @Access3DLab on LinkedIn, Twitter, Instagram, Facebook and Sketchfab.

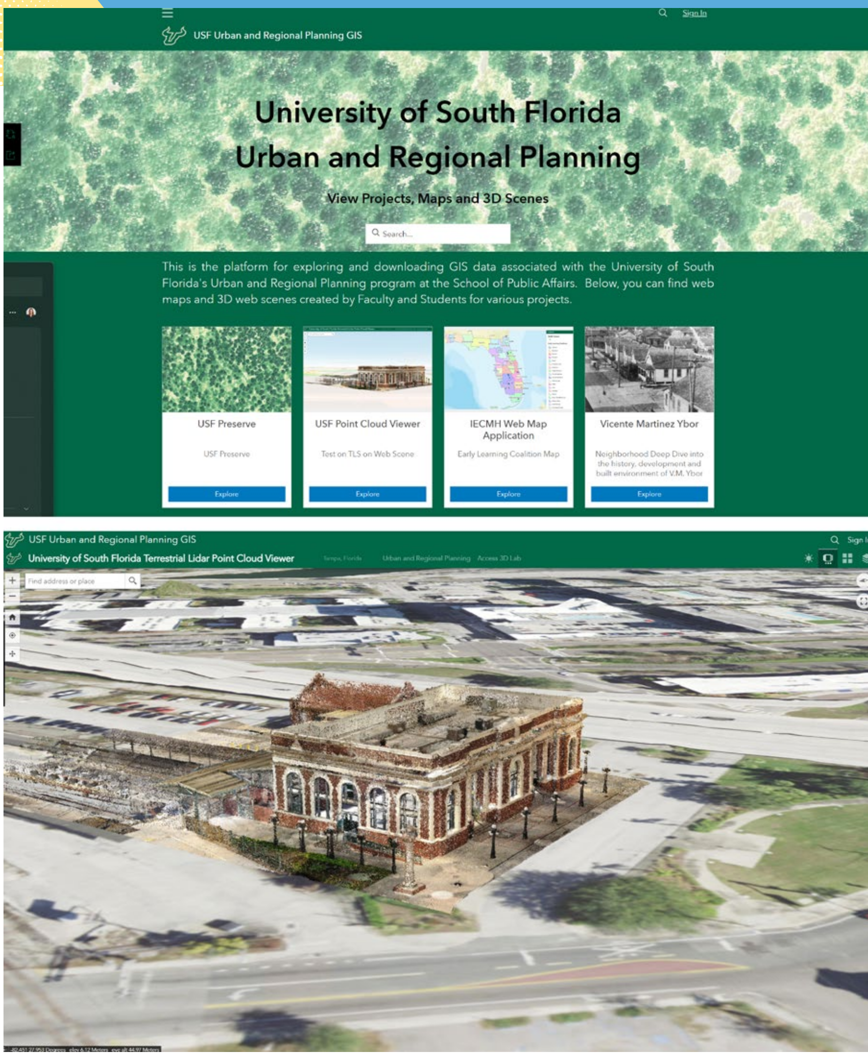
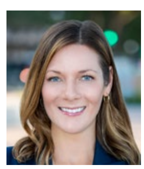


Figure 7: The USF Urban and Regional Planning terrestrial point cloud viewer. The top image shows the landing page, and the bottom image shows a georeferenced terrestrial laser-scan of Union Station in Tampa.

Steven Fernandez, MA, GISP, CCM is a Certified GIS Professional with 23 years' experience in GIS and urban planning. He is a Research Assistant Professor in the Master of Urban and Regional Planning Program at USF. Steven is also a Hillsborough County Planning Commissioner and the Education Chairman of the Florida Association of Cadastral Mappers.



Laura K. Harrison, PhD, MA, RPA is a Research Assistant Professor and Director of USF's Access 3D Lab. She has over 15 years of experience on 3D scanning, digital heritage and archaeology projects throughout Europe and the United States. She is also the Associate Editor of *Studies in Digital Heritage*.

Lidar Looks Lively in the Sunshine State

A synopsis of the 13th UF/FL-ASPRS Lidar Workshop

The Florida Region of the American Society for Photogrammetry and Remote Sensing (FL-ASPRS) and the University of Florida Geomatics Division have been hosting bi-annual "Lidar Workshops" since spring 2016. The Fall 2022 workshop was held at the Mid-Florida Research & Education Center of the University of Florida's Institute of Food and Agricultural Sciences at Lake Apopka on 17 November 2022. The workshops are open to ASPRS members and non-members alike, for either in-person or virtual participation. The Fall 2022 Workshop hosted 75 on-site participants and 255 virtual attendees.

The UF/FL-ASPRS workshops serve as both a bi-annual FL-ASPRS Region meeting and as educational outreach to the general photogrammetry and remote sensing community. With respect to the ASPRS mission statement, "to promote a balanced representation of the interests of government, academia and private enterprise"[1], the program focuses on these three sectors with presentation sessions devoted to each. Below is an outline of the sessions with synopses of each.

1 asprs.org/asprs-organization/mission-statement

BY AL KARLIN

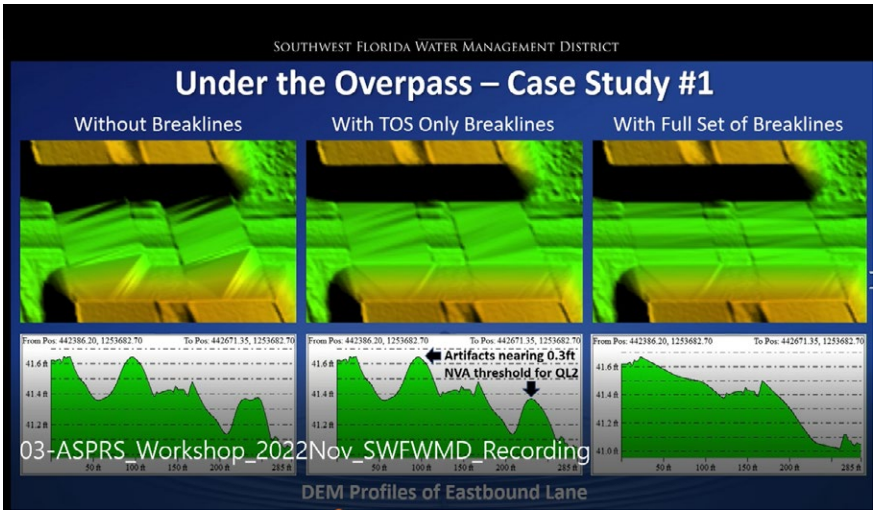
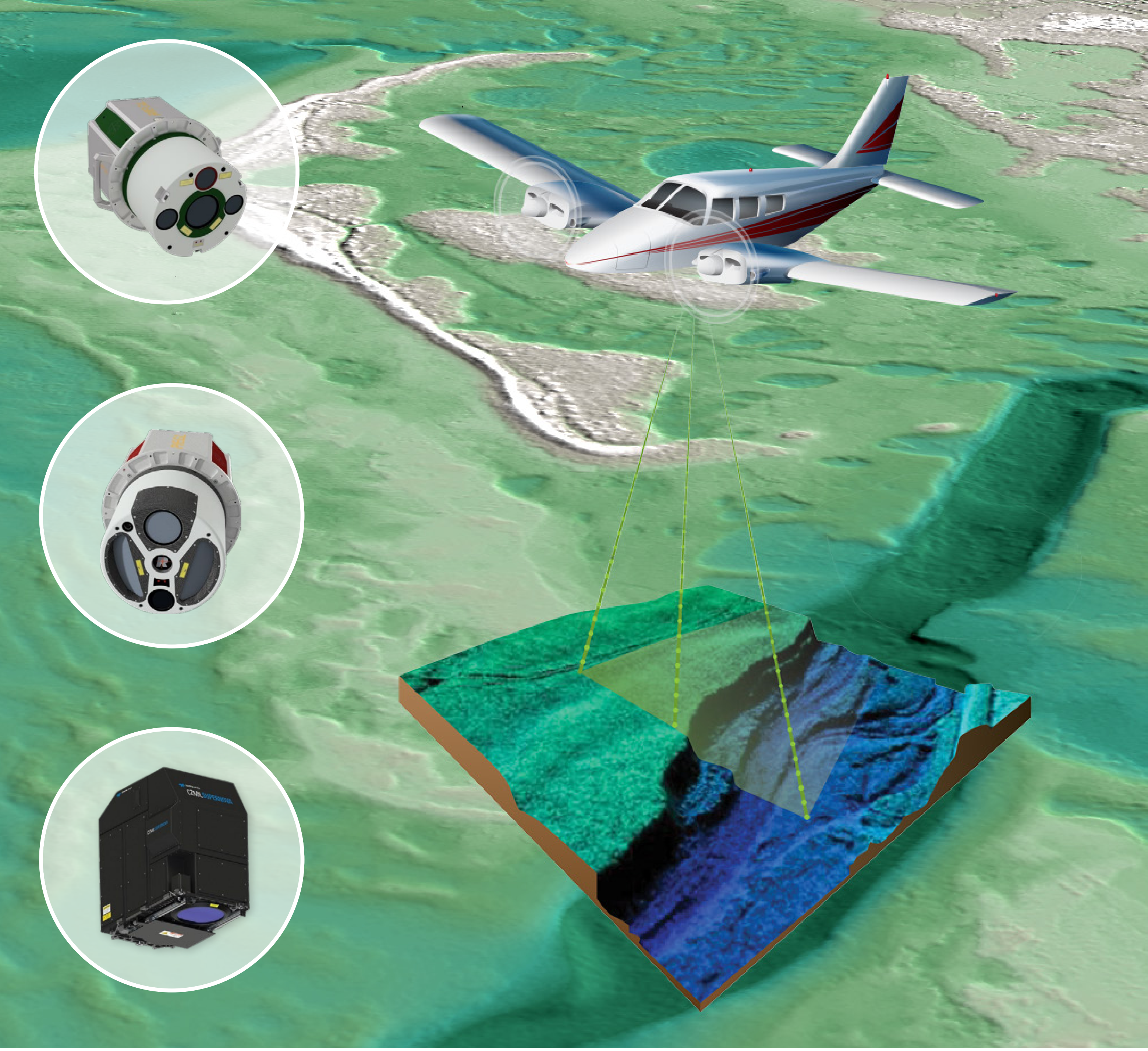


Figure 1: Digital elevation model overpass interpolation issues arising from lidar data voids. Standard Breaklines at the Toe of Slope (TOS) do not significantly improve the DEM as compared to no breaklines. However, a full set of breaklines that also includes the centerline and edges of pavement produces an accurate ground surface for water flow.

Session 1: State and Federal Updates

The State and Federal Updates generally start with updates from the five Water Management Districts in Florida. However, as the two major lidar projects resulting from Recovery funding for Hurricane Irma (the peninsula of Florida) and Hurricane Michael (most of the panhandle of Florida) are concluding, there were no Water Management District project updates.

Southwest Florida Water Management District: Nicole Hewitt used the timeslot to discuss the importance of (1) accounting for lidar data voids resulting from water and anthropogenic structures, and (2) the need for accurate breaklining in the construction of digital elevation models (DEMs) that are to be used for surface water modeling. Nicole began by describing the interpolation issues that arise when waterbodies are not properly interpolated into the DEM. Then, she detailed two scenarios where the "standard" USGS 3DEP breaklines are not sufficient to produce proper surface water flow, emphasizing the importance of correct breakline placement for bridges and overpasses (**Figure 1**).



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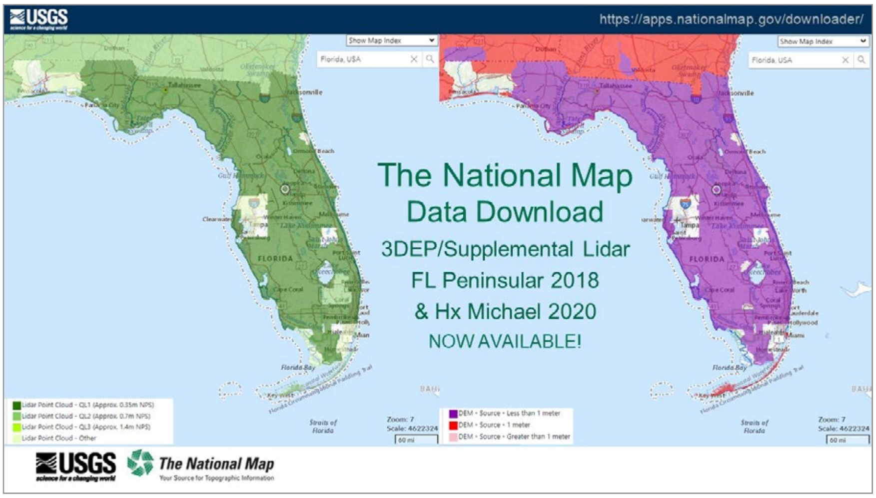


Figure 2: The National Map Data Download, recently updated by USGS, showing the Florida Peninsular and Hurricane Michael lidar data.

U.S.Geological Survey: Alexandra (Xan) Fredericks, the USGS National Map Liaison assigned to Florida, presented an update to the Florida lidar data available on The National Map, showing that the entire FL Peninsular 2018 and the Hurricane Michael 2020 data are currently available (**Figure 2**).

Xan continued to discuss the 3D Nation Vision and the 3D National Topography Model (3DNTM). She presented a brief summary of some of the results of the recently released 3D Nation Elevation Requirements & Benefits Study. She concluded by noting the importance of collaboration and presented a map showing the names of the USGS National Map Liaisons (usgs.gov/ngp-user-engagement-office).

Florida Coastal Mapping Program (FCMaP): Dr. Cheryl Hapke, University of South Florida College of Marine Science, discussed the evolving mission of the Florida Coastal Mapping Program. Started in 2017 as a steering committee to identify statewide needs in coastal mapping and conduct a gap analysis of existing coastal seafloor data, followed by a statewide stakeholder prioritization study, this is now solidifying its five-year strategic plan. In place of the steering committee, a FCMaP Science and Technical Advisory Council was stood up, composed of the same membership as the steering committee, but with distinct terms of reference to distinguish FCMaP (a coordinating body) from the Florida Seafloor Mapping Initiative (data collection funded by the Florida Department of

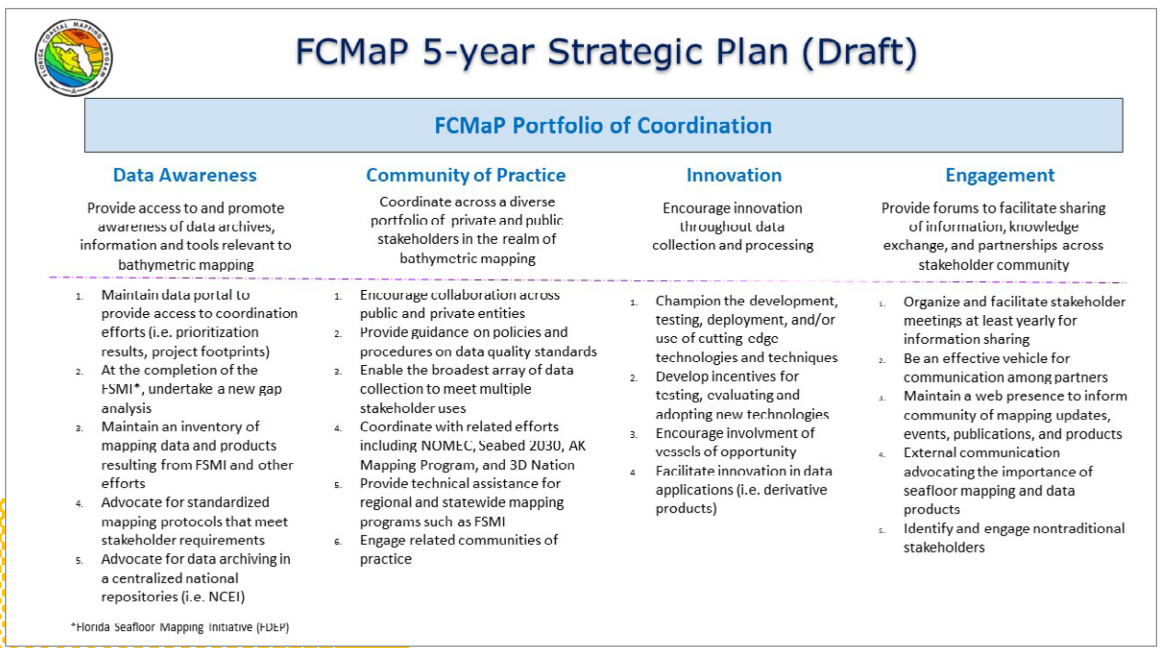


Figure 3: Draft FCMaP 5-year Strategic Plan as presented at the Workshop.

Environmental Protection (FDEP)). Cheryl presented a draft of the FCMaP 5-year Strategic Plan (**Figure 3**).

She concluded her presentation by emphasizing the need for coordination across a diverse portfolio and engagement by both organizations and individual stakeholders, to make the Florida Seafloor Mapping Initiative successful.

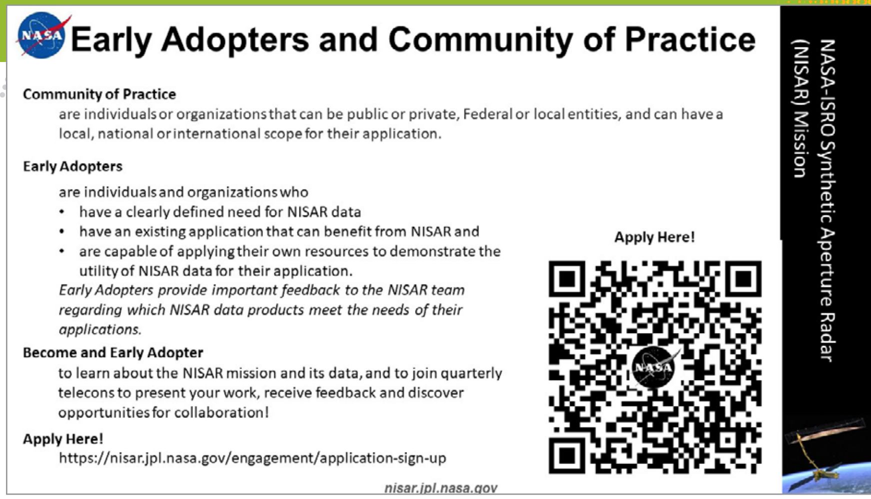


Figure 4: Web-link and QR Code for joining the NISAR Early Adopters and Community of Practice.

NASA-Jet Propulsion Laboratory: Dr. Batu Osmanoglu provided the update on the NISAR launch dates and Community of Practice. He was happy to inform the Workshop that the much-anticipated launch for the NISAR satellite is scheduled for 29 January 2024. He provided some additional information on test data available to early adopters, as well as potential data products with schedules. He briefly discussed the recent NISAR Science Community Workshop in Pasadena, California, where over 290 people participated. Batu ended his presentation with information on how to join the Early Adopters and Community of Practice (**Figure 4**).

National Oceanic and Atmospheric Administration (NOAA): NOAA is currently conducting two large-area topobathymetric lidar mapping projects in Florida, one focused on mapping over 615 square miles of the Indian River Lagoon with the St. Johns River Water Management District (SJRWMD) and FDEP as partners, and the other focused on mapping approximately 1373 square miles in the Big Bend Region on the Gulf Coast of Florida.

Indian River Lagoon (IRL): Dr. Charles Jacoby representing SJRWMD provided the update on this project. He started by noting several of the issues surrounding the bathymetry of IRL, specifically the loss of seagrass, the unstable sediments and how the bathymetry affects management decisions. The project includes topobathymetric lidar and digital imagery for approximately 1663 miles of shoreline in an area of approximately 616 square miles (**Figure 5**). He noted that although most of the lidar was collected using a Teledyne Geospatial CZMIL sensor, the restricted area around Cape Canaveral Space Force Station would be collected with a NOAA RIEGL 880G sensor. The project is scheduled for completion in May 2023.

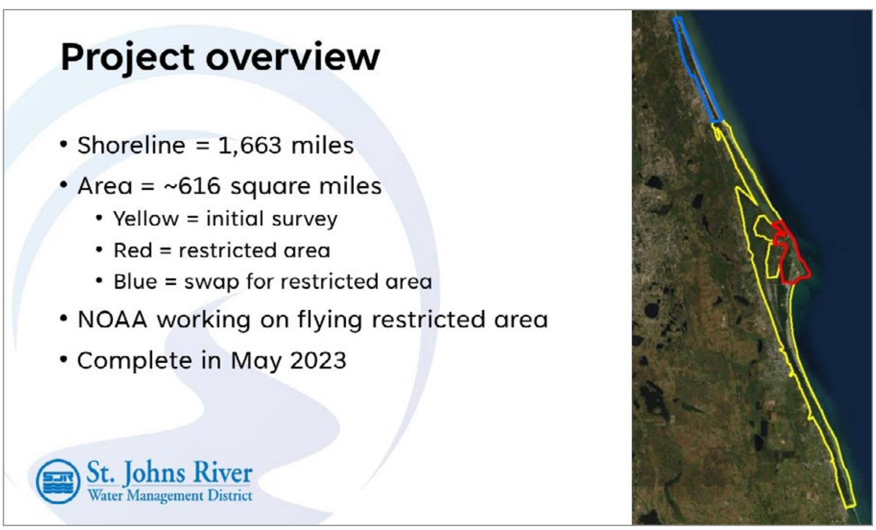


Figure 5: Overview of the NOAA/SJRWMD/FDEP Indian River Lagoon topobathymetric lidar and imagery mapping project.

Tampa Bay and Big Bend: Emily Klipp from Dewberry provided the update on two Gulf Coast of Florida NOAA topobathymetric lidar projects (**Figure 6**). Northern Tampa Bay (FY2020) was mapped using the RIEGL 880G sensor and Southern Tampa Bay (FY2021) was mapped with a Teledyne Geospatial CZMIL sensor. Both projects are now complete and the data are available on the NOAA Digital Coast (coast.noaa.gov/digitalcoast/). She continued to highlight the NOAA/Big Bend, approximately 1,373 square mile, topobathymetric lidar mapping that is

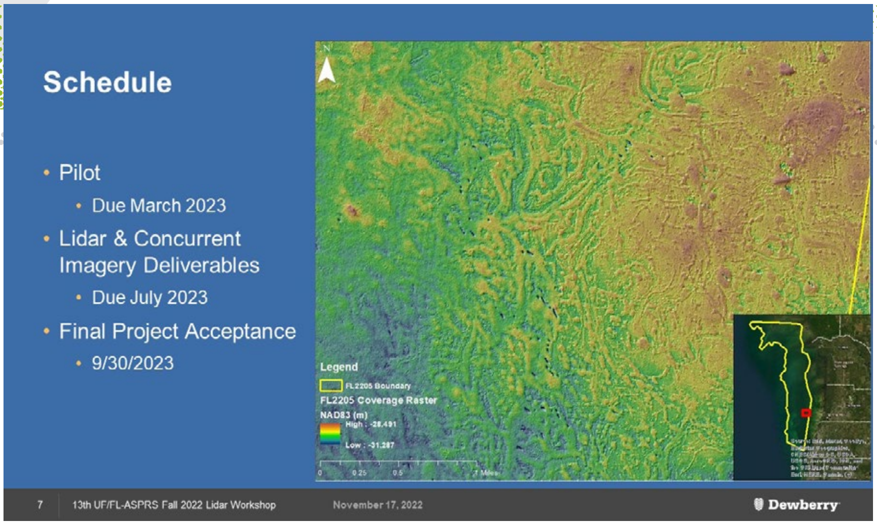


Figure 6: Topobathymetric DEM showing bathymetry of an area recently collected in the Big Bend area of Florida.

currently underway. Dewberry is using a Teledyne Geospatial CZMIL SuperNova for this mapping. She highlighted the Customer Data Portal and Dashboard that were constructed to permit daily updates on the project's progress.She concluded by showing the DEM for an area recently collected (**Figure 6**). The project is scheduled to be completed by the end of September 2023.

Session 2: Keynote Address—Brett C. Wood: Geospatial mapping and data management at FDOT

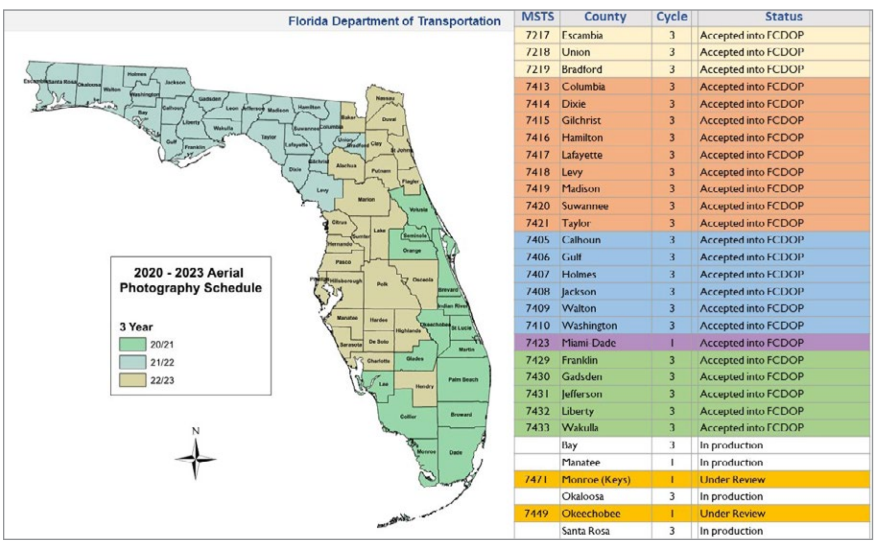
Each workshop includes an invited "Keynote Speaker." Brett Wood is the State Surveyor for the Florida Department of Transportation (FDOT) and manages the Central Surveying and Mapping Office (CSMO) located in Tallahassee. Brett has over 39 years' experience in surveying and mapping and became a Licensed Surveyor and Mapper in 1997. Prior to this he served as Mobile Surveying & Mapping Manager within the CSMO. Brett came to the Department in 2009 from the private sector, specializing in GNSS and remote sensing technologies.

Brett opened his presentation by describing the administrative structure of FDOT and its historical role in state topographic mapping. Florida was one of the early adopters of aerial mapping and has been using photogrammetry since 1949. FDOT is responsible, under Florida Statute 373.012, for topographic mapping. Starting by conducting the aerial surveys in-house using state-owned film-based metric cameras, then moving to digital cameras in the early 2000s, FDOT has a long history in remote sensing. By 2014, CSMO had shifted direction by employing mobile mapping technologies and outsourcing aerial surveying and mapping services to the consultant community. FDOT is currently working with the Florida Division of Revenue to conduct aerial orthophotography of the entire state on a three-year rotating schedule (**Figure 7**).

Brett went on to discuss FDOT's methods and procedures for quantifying the accuracy of 3DEP lidar for use in roadway surveying. He concluded his presentation by discussing the Florida Permanent Reference Network (FPRN) and the evolving role of CSMO (**Figure 8**).

Session 3: The Florida Seafloor Mapping Initiative (FSMI)—Topobathymetric Workshop

In 2021, $100M was provided to FDEP to capture statewide bathymetric data. The intent of the project is to capture topo-bathymetric lidar, to the greatest extent possible in the 0–20 m depth range, and then use acoustic technologies to map in the 20-200 m range. FDEP's Office of Resilience and Coastal Protection (ORCP) was charged with the management and coordination of the project.



MSTS	County	Cycle	Status
7217	Escambia	3	Accepted into FCDOP
7218	Union	3	Accepted into FCDOP
7219	Bradford	3	Accepted into FCDOP
7413	Columbia	3	Accepted into FCDOP
7414	Dixie	3	Accepted into FCDOP
7415	Gilchrist	3	Accepted into FCDOP
7416	Hamilton	3	Accepted into FCDOP
7417	Lafayette	3	Accepted into FCDOP
7418	Levy	3	Accepted into FCDOP
7419	Madison	3	Accepted into FCDOP
7420	Suwannee	3	Accepted into FCDOP
7421	Taylor	3	Accepted into FCDOP
7405	Calhoun	3	Accepted into FCDOP
7406	Gulf	3	Accepted into FCDOP
7407	Holmes	3	Accepted into FCDOP
7408	Jackson	3	Accepted into FCDOP
7409	Walton	3	Accepted into FCDOP
7410	Washington	3	Accepted into FCDOP
7423	Miami-Dade	1	Accepted into FCDOP
7429	Franklin	3	Accepted into FCDOP
7430	Gadsden	3	Accepted into FCDOP
7431	Jefferson	3	Accepted into FCDOP
7432	Liberty	3	Accepted into FCDOP
7433	Wakulla	3	Accepted into FCDOP
	Bay	3	In production
	Manatee	1	In production
7471	Monroe (Keys)	1	Under Review
	Okaloosa	3	In production
7449	Okeechobee	1	Under Review
	Santa Rosa	3	In production

Figure 7: FDOT three-year rotating aerial survey of Florida.

In mid-2022 ORCP solicited a Response for Proposals/Qualifications to perform the mapping and selected five consulting firms for the project. As each firm brings a unique suite of qualifications to the project, the FL-ASPRS Board of Directors invited a representative from each of the selected firms to present their technologies to the Workshop. Below (in alphabetical order) are the firms, their representative speaker, and a note regarding their technologies.

- Avior Geospatial (aviorgeo.com): Vladimir Kadatskiy—RIEGL VQ-840G topobathy lidar
- Dewberry (Dewberry.com): Emily Klipp—Teledyne Geospatial CZMIL SuperNova (x3); RIEGL VQ-880-GII, VQ-880GH, VQ-880G+; 15 acoustic/sonar deep and shallow water sensors
- Fugro (fugro.com/our-services/asset-integrity/mapping-and-surveying/geospatial-gis-solutions): Keith Owens—satellite derived bathymetry; Rapid Airborne Multibeam Mapping System (RAMMS); crewed and uncrewed surface vehicles with acoustic sensors
- Tetra Tech, Inc. (tetratech.com): Renee Walksley and Robert Feldpausch—Leica Chiroptera 4X, RIEGL VQ-840G, Teledyne Geospatial CZMIL SuperNova; R2Sonic deep water and shallow water acoustic sensors
- Woolpert, Inc. (woolpert.com/services/geospatial): Jeff Lovin—satellite derived bathymetry, Leica Chiroptera 4X, Leica Hawkeye, RIEGL VQ880-G series; numerous deep-water and shallow-water acoustic sensors.

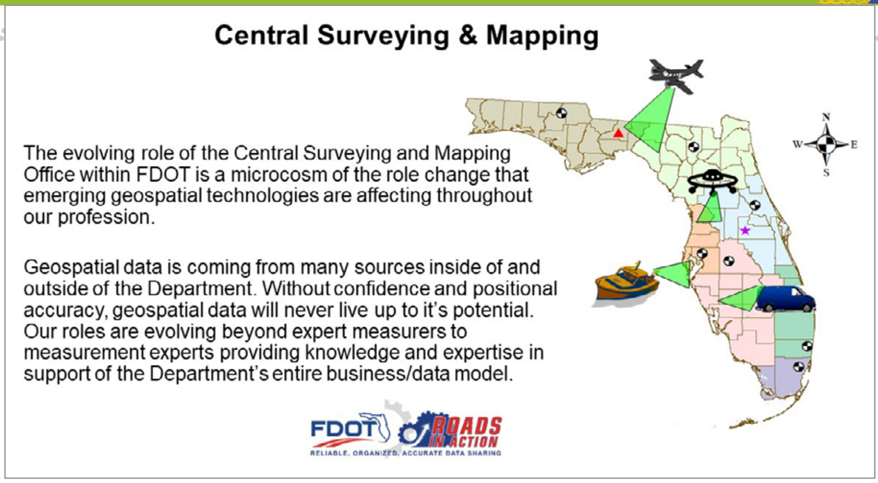


Figure 8: The changing role of the Central Surveying and Mapping Office at the Florida Department of Transportation.

Session 4: Sponsors' presentations

FL-ASPRS has been soliciting corporate sponsors for the Lidar Workshop to help defray costs for the meetings; coffee, snacks, and lunch are all provided to participants, along with the venue and other services. The Board of Directors has developed a three-tier system so that corporate sponsors can choose the level of their support. While all levels of sponsorship receive recognition at the workshop, the sponsor's corporate logo on the program and all promotional materials, Platinum-level sponsors are provided a 10-minute timeslot to present their services. The sponsors below are identified, in alphabetical order by sponsorship-level. Returning sponsors are identified with an asterisk (*; **Figure 9**):

- Platinum-level: Dewberry*, Echo81, GPI GeoSpatial*, Langan*, McKim & Creed, MythosAI, Pointerra*, RIEGL* and TopoDOT;
- Gold-level: NV5 Geospatial*, Pickett and Associates*, Surdex Corp.*, SurvTech;
- Silver-level: 3002, Inc.* and TileDB*.

Figure 9: UF/FL-ASPRS Fall 2022 Workshop Sponsors.

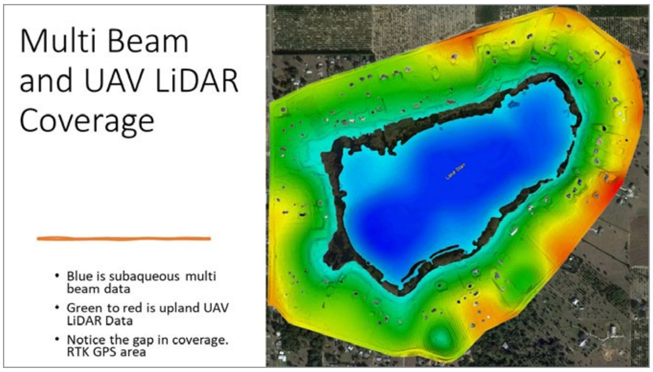


Figure 10: Lake Starr, Polk County, Florida showing areas surveyed by UAV lidar, multi-beam sonar and the "gap area" between the remote sensing surveys.

Figure 11: Lake Starr showing "gap area" with RTK-GNSS elevations.

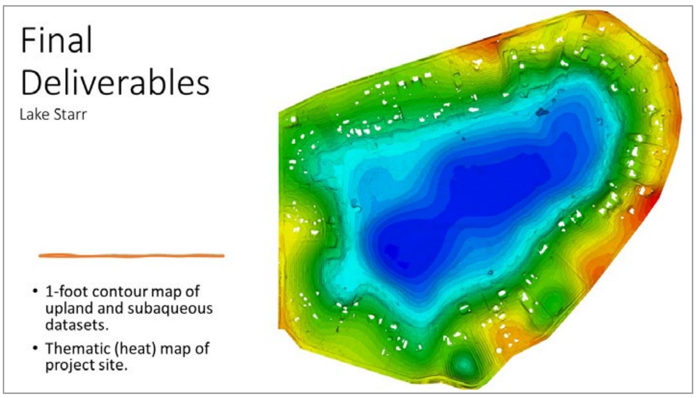


Figure 12: Digital terrain model for Lake Starr constructed from UAV-lidar, RTK-GNSS, and multi-beam sonar.

Session 5: Academic presentations

David O'Brien, with Mark Bickel, Ken Comeaux, Chase Comeaux, Darron Goss, and Jason Ellard: Surveying and mapping Florida fresh water lakes with UAV-lidar, multi-beam sonar, and RTK GPS—SurvTech solutions
David presented a project in cooperation with Florida Water Management Districts mapping four freshwater lakes in Polk County (Lake Starr, Lake Eagle, Lake McLeod and Lake Wailes) and three freshwater lakes in Highlands County (Lake Angelo, Lake Denton and Lake Tulane). The significance to the workshop is that these lakes were mapped using a combination of UAV-lidar, in the uplands, multi-beam sonar in the subaqueous portions, and the gaps between lidar and sonar were filled in with conventional real-time kinematic (RTK) GNSS technology. The goal of the mapping was to construct a seamless digital terrain model (DTM) from the uplands to the lake bottom. Rather than detail each lake, David focused on Lake Starr in Polk County, Florida (**Figure 10**).

In the case of Lake Starr, the "gap area" was filled with RTK-GNSS survey (**Figure 11**) and cross-sections through the three datasets were evaluated for consistency. The final DTM (**Figure 12**) was constructed from the three survey datasets.

David concluded his presentation by showing the workshop representative cross-section profiles and composite DTMs for other selected lakes in the project.

Laura K. Harrison, Steven Fernandez, and Kylie Dillinger: Terrestrial lidar for coastal heritage at risk—University of South Florida.
Dr. Laura Harrison gave the final presentation of the workshop, focusing on using terrestrial lidar to assess coastal heritage sites at risk for flooding related to sea-level rise. Egmont Key in Pinellas County, Florida is a 500-acre island located where the Gulf of Mexico meets Tampa Bay. It contains several irreplaceable cultural sites and this study focused on one, the Battery McInstosh site on the northern end of the island (**Figure 13**). Over the last 150 years, the island has experienced loss of over 50% of its landmass as a result of erosion and sea-level rise: thus preserving cultural features, such as the Battery McIntosh, is becoming increasingly important.

Lidar scanning workshops for both students and concerned citizens were conducted to train staff for the terrestrial scanning of Battery McIntosh.

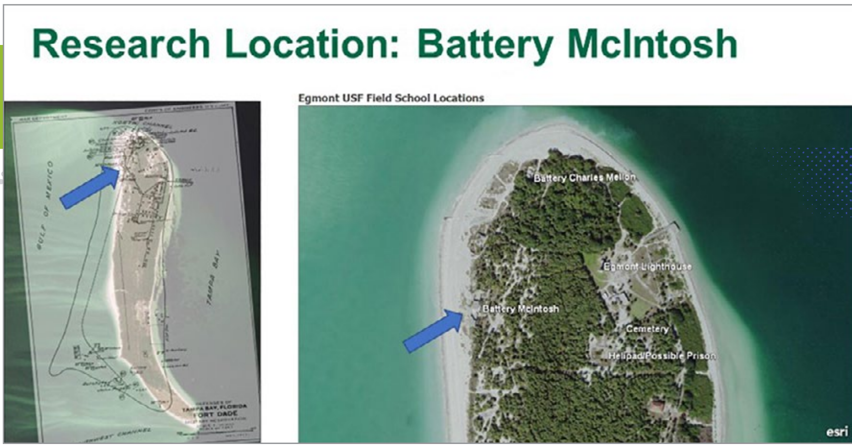


Figure 13: Battery McIntosh location on Egmont Key (right) and an overlay map showing loss of landmass during the past 150 years (left).

Figure 14: Battery McIntosh exposed based on NOAA high-water predictions for 2050.

Figure 15: Battery McIntosh exposed area based on NOAA high-water predictions for 2080, showing high-water encroachment on Battery.

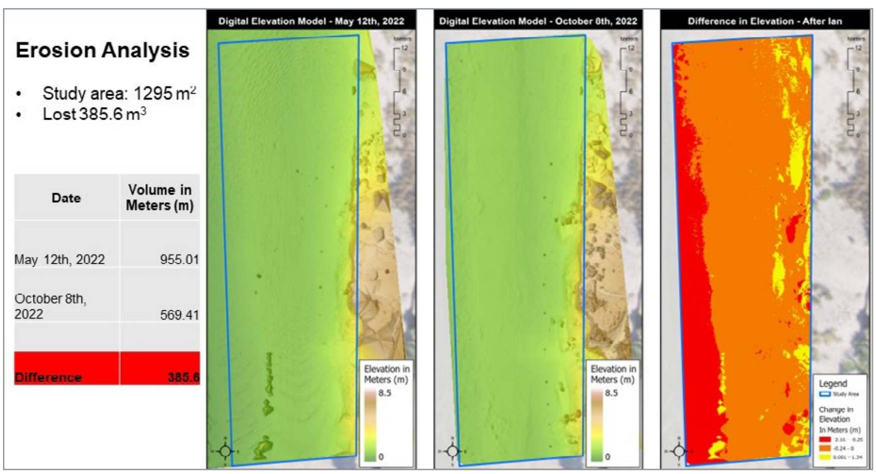
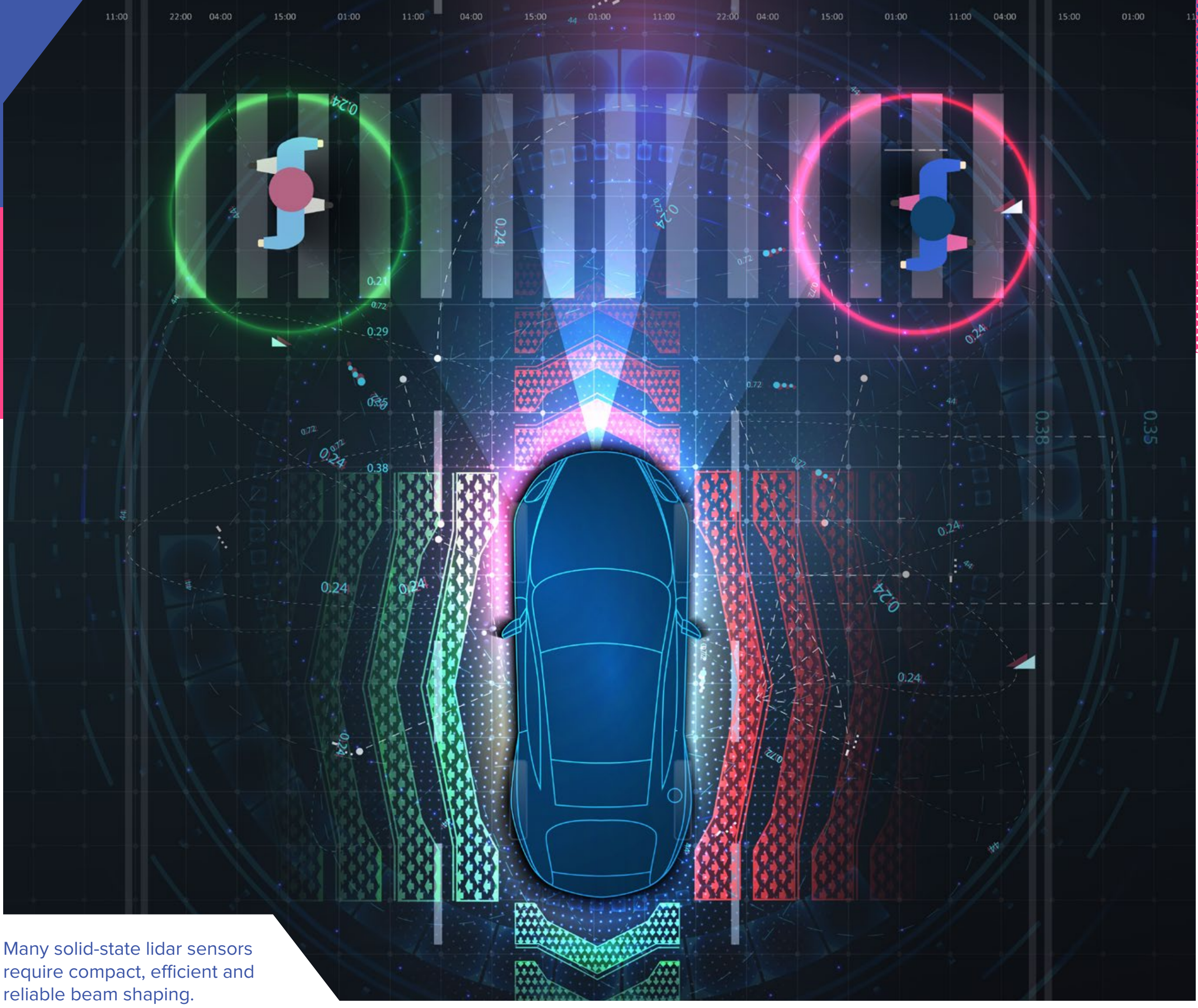


Figure 16: Erosion analysis of Egmont Key, Pinellas County, Florida before (May 2022) and after (October 2022) Hurricane Ian.

The scans were initially conducted in May 2022. The data was georeferenced and processed into a LAS point cloud and a "fly-through" visualization was constructed. NOAA data was used to estimate the high-water scenarios expected for 2050 (**Figure 14**) and 2080 (**Figure 15**).

Laura concluded the presentation with an update on the erosion of Egmont Key resulting from Hurricane Ian's landfall on 28 September 2022. The staff conducted one day of fieldwork, collecting 28 lidar scans on 8 October 2022. Direct shoreline measurements revealed a loss of over 385 cubic meters of shoreline resulting from erosion caused by the hurricane (**Figure 16**).

Alvan "Al" Karlin, Ph.D, CMS-I, GISP is a senior geospatial scientist at Dewberry, formerly from the Southwest Water Management District (SWFWMD). While at SWFWMD he managed all of the remote sensing and lidar-related projects in mapping and GIS. With Dewberry, he serves as a consultant on Florida-related lidar and imagery projects, as well as general GIS-related projects. He has a Ph.D in computational theoretical genetics from Miami University in Ohio. He is a Director on the Board of the Florida Region of ASPRS, an ASPRS Certified Mapping Scientist—Lidar, and a GIS Certification Institute Professional.



Many solid-state lidar sensors require compact, efficient and reliable beam shaping.

Enhancing Visual Intelligence with Efficient Beam Shaping for Automotive Lidar

How to achieve efficient, uniform illumination and iterate quickly with a customized solid-state lidar design

BY JOHN **WILSON**

As automobiles become more technologically sophisticated, they require ever increasing information from the outside world—along with information about the driver and passengers inside the vehicle. New sensors enable higher-speed data acquisition and higher-resolution

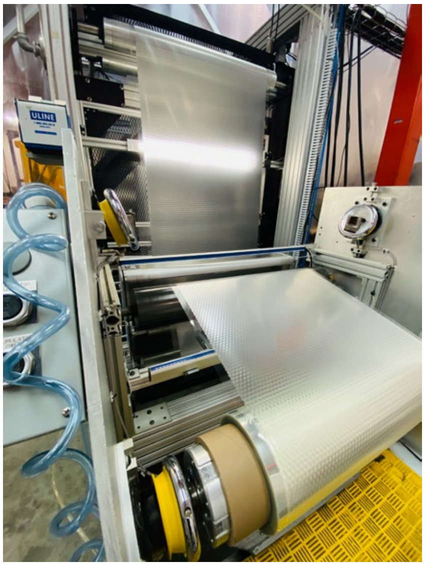
imaging of surrounding environments, paving the way for autonomous or semi-autonomous driving and creating more effective passenger monitoring.

Flash lidar systems have become a popular tool for developers to advance new data-driven applications thanks to their simplicity and low cost—a strong light source, however, is required for effective deployment. Micro lens array (MLA) technology has emerged in parallel with lidar systems as a tool to optimize the efficient use of light from the lidar source.

This article provides more insights on the benefits of MLA technology and an overview of how an iterative approach can be used for quickly converging on high-performing optical designs.

The lowdown on lidar optics

Flash lidar uses a pulse of light, usually emitted from a vertical cavity surface emitting laser (VCSEL) array, coupled with a time-of-flight (ToF) camera, to detect objects around a vehicle. Automotive developers often position these systems at strategic points around a vehicle to enable a 360° view. The VCSEL array is a semi-collimated source and requires lidar beam shaping to achieve the specified field of view (FOV)



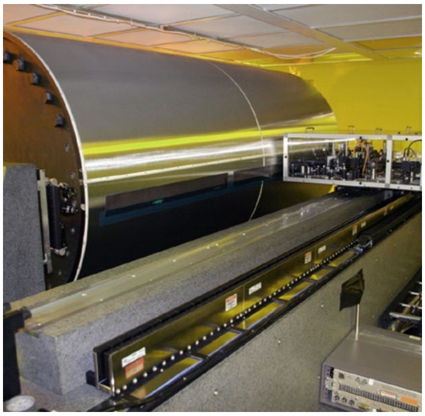
A roll-to-roll photo-replication process helps facilitate mass production.

and 3D mapping for the surrounding environment.

Conventional lighting diffusers do not typically perform well in automotive lidar systems because they tend to lack uniform illumination and can result in wasted light output. MLA diffusers offer a way for developers to overcome this hurdle using complex shapes to achieve both uniform and efficient illumination over a desired FOV for a range. The solutions are an attractive option for applications where a cost-effective and efficient light management solution is needed.

Efficient, uniform illumination

MLA technology consists of microscale lenses that are engineered to manage and shape light for the visual intelligence needs of various applications, including

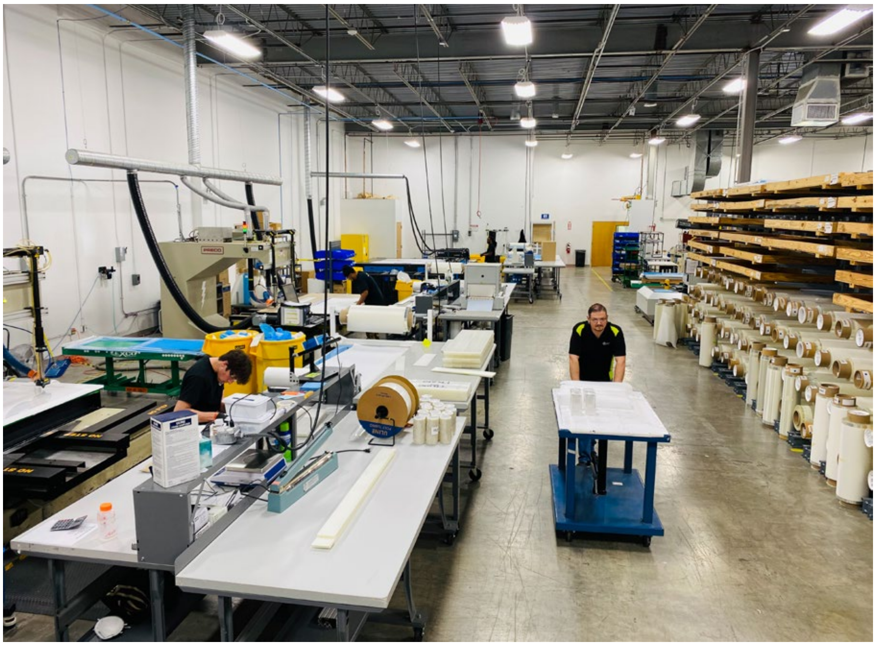


BrightView's custom grayscale photolithography system creates MLAs pixel by pixel.

consumer and automotive displays, lidar, sensing systems and LED lighting. These solutions can take on a variety of shapes and sizes to suit the required light output based on a given light input.

Examples of MLA distributions for vehicle applications include a rectangular FOV profile, which is generally for long- or mid-range lidar applications, and wide-spreading profiles with angle bend for shorter-range lidar applications. They can also be custom-made for a particular application or device.

MLA solutions are created using a grayscale lithography technique to individually "write" patterns into a specially formulated, photosensitive polymer. These patterns are converted into products using a high-capacity, roll-to-roll production process (sometimes called a continuous web process). The method helps establish a completed diffuser product from a roll of bare plastic without having to cut the initial roll into sheets to be processed one at a time.



From the production rolls, a final product is cut to customer specifications.

The final roll can then be easily stored or shipped, and later cut to whatever size a given application needs.

Tackling complex designs

When it comes to determining the beam specifications for a particular application, there may not always be a clear-cut way to calculate the necessary optical surface for a desired target profile. This can present a design challenge for developers, causing optical modeling to become very slow with one design taking hours to simulate.

For a more iterative approach, developers should consider partnering with a technology provider that can work closely in collaboration through the design and tooling process. BrightView's tooling system for MLA applications is designed to enable rapid iteration through creation and characterization of many versions (~200) of a lens design in a single 8-12 hour run cycle. The process can be repeated, while varying the parameters, if necessary, until specifications are met.

The following is a general overview of BrightView's tooling process, which is engineered to take customers from the design process through production:

- An MLA design is created via in-house software
- The software transfers the design to BrightView's custom grayscale photolithography digital tooling system
- A high-volume, roll-to-roll photo-replication process is used to generate mass production
- Rolls can be converted to individual parts using laser cutting, die cutting or precision computer numerical control routing. Highly consistent tooling is created from the primary tool.

Through this iteration process a single MLA file can be created for a lens design and seamlessly transitioned into production. BrightView's large-scale production tooling runs in synch with the roll-to-roll mass production line in its manufacturing facility.

Prototype to production

Flash lidar systems will only increase in proliferation as innovation in autonomous and semi-autonomous vehicles moves forward. Additionally, applications such as in-cabin sensing continue to advance with industry efforts to enhance automobile safety by monitoring driver alertness as well as applications such as gesture control. These applications also use VCSEL arrays that require beam shaping and direction management.

MLA solutions serve as a resource for advancing automotive applications with optimized optical designs that leverage customizable light bend and beam shaping solutions available in a variety of form factors. As innovation continues to drive the industry forward, the technology can help developers achieve the right level of visual intelligence to be a leader in the competitive race ahead.

John Wilson, PhD is a member of the technical staff in the R&D group at BrightView Technologies, where he designs high-performance micro-optics for lidar, remote sensing, and machine vision applications. Please send technical questions, business inquiries or other requests to jwilson@brightviewtech.com.

Figure 1: Test area with the village of Hessigheim and the ship lock area.

UAV Point Clouds at Millimeter Accuracy

Hybrid georeferencing of images and lidar point clouds for deformation monitoring

This is a slightly shortened version of the published paper by the same authors, which is listed as the third reference in the bibliography at the end of the article.

Introduction

Originally, photogrammetry and laser scanning developed as competing disciplines, providing specific advantages and using individual processing pipelines while aiming at the airborne collection of 3D point clouds. As an example, lidar sensors measure multiple responses of the reflected signal, which is advantageous to measure both on and below vegetation. On the other hand, georeferencing accuracy is basically defined by the accuracy of the trajectory as measured by an integrated GNSS/IMU system. In combination with the accuracy of lidar range measurement of about one centimetre, this limits the accuracy of lidar point clouds captured from a moving platform to a few centimetres. In contrast, Multi-View-Stereo-Matching (MVS) of overlapping images potentially provides point cloud accuracies that directly correspond to the ground sampling distance (GSD) of the imagery. Thus, a proper selection of the captured image scale enables

NORBERT **HAALA,** MICHAEL **KÖLLE** AND MICHAEL **CRAMER**

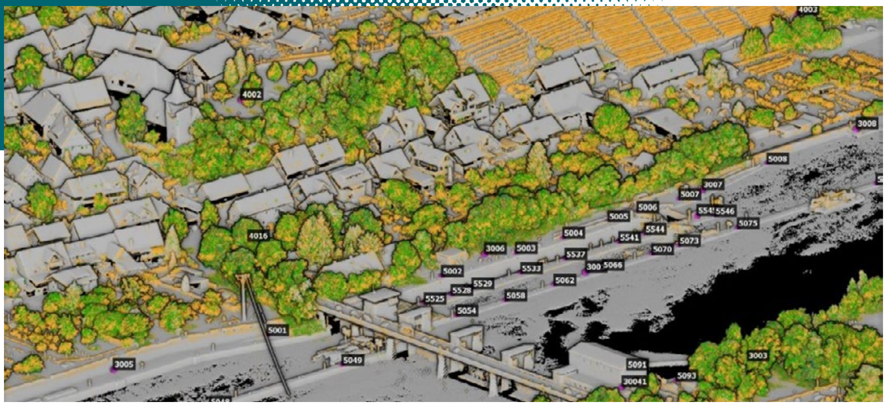


Figure 2: Lidar point cloud captured at the ship lock area with color coding representing the number of returns and labels displaying IDs of signalized targets.

direct control of geometric accuracies. However, this presumes suitable redundancy during image matching, which can be hindered, for example, by occlusions or texture-less images in certain scenarios. In order to benefit from the respective advantages, systems for joint collection and evaluation of lidar and image data are becoming commonplace. This allows for applications like the collection of UAV point clouds at millimeter accuracy, which have not been possible so far. We demonstrate this high-accuracy data collection in the context of a project for the deformation monitoring of a ship lock due to geological subsidence.

Figure 1 depicts our test site, which includes a ship lock and its facilities, the river Neckar and the riparian area as well as vegetated areas, farmland, and residential areas of the surrounding village of Hessigheim, Germany. In this area, geological subsidence results in local displacements of about 6-10 mm/year. These changes are monitored by terrestrial data collection twice a year using geodetic instruments such as levels, total stations and differential GNSS (Kauther and Schulze, 2015). This was the reason to establish a network of pillars and marked points for signalization. However, economic reasons limit these engineering geodesy techniques to measures at specific parts of built structures or natural objects. In contrast, airborne platforms allow for area-covering 3D measurement. Since photogrammetric data collection at millimeter scale requires imagery at a similar resolution, this requires the low flying altitudes that are feasible with UAV platforms. If signalized control points are additionally available, photogrammetric image processing can meet such accuracy specifications. However, our project aims at the measurement of subsidence of terrain surfaces, which are covered to a considerable extent by vegetation such as trees, bushes and shrubs. This motivated the additional use of lidar due to its ability to penetrate such vegetation. The point cloud of our test area is depicted in **Figure 2**, with color coding representing the number of reflections of the respective lidar pulse. Such multiple returns are measured and

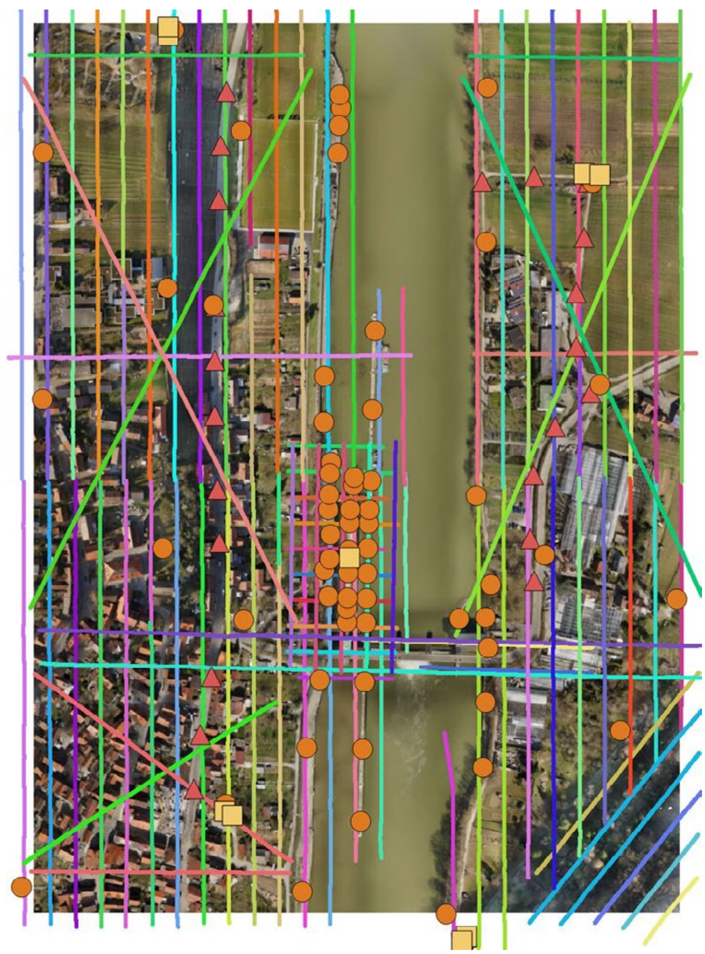


Figure 3: Area of investigation with captured lidar strips (colored individually), lidar control planes (dark yellow squares), checkerboard targets (orange dots) and non-signalized height check points (red triangles).

analyzed during full-waveform recording. Furthermore, the labels represent the IDs of the signalized points available in the test area. While this network was originally established during terrestrial monitoring, it is also applied during our accuracy investigations of UAV-based data collection. Clearly, these signals are rather dense in the ship lock area, which is the main object of interest.

For deformation monitoring, multiple UAV flights were captured for a period of three years. Joint orientation of laser scans and images in a hybrid adjustment framework then enabled 3D point accuracies at millimeter level. This process integrates photogrammetric bundle block adjustment with direct georeferencing of lidar point clouds and thus improves georeferencing accuracy for the lidar point cloud by an order of magnitude.

Figure 4: Ship lock and photogrammetric control plane (PCP) on a pillar and lidar control plane (LCP).

Test set-up and data collection

Figure 3 depicts the planned flight configuration for our test area. The ortho image depicts our area of interest, which features a maximum site extension of 570 m (east-west) x 780 m (north-south). In addition to the respective lidar strips, which are coloured individually, the figure includes the distribution of the signalized ground points already shown in **Figure 2**.

In **Figure 3**, so-called photogrammetric control planes (PCP) are represented by orange circles. **Figure 4 (left)** gives an example of such a checkerboard signal. These targets were scattered within the test area and served as control or check points during automatic aerial triangulation (AAT) of the imagery. In our test area the checkerboards were mounted on pillars, tripods, and directly on the ground. They have a diameter of 27 cm in order to enable automatic measurement of corresponding image coordinates. **Figure 4 (right)** depicts a so-called lidar control plane (LCP). These signals, represented by dark yellow squares in **Figure 3**, are constructed by two roof-like oriented planes with each roof plane featuring a size of 40 cm x 80 cm. Thus they consist of distinct planar geometries with known position and orientation in space. Their inclination of 45° provides both a vertical and a horizontal component to be analyzed during accuracy investigations on lidar point georeferencing. In contrast, the horizontal PCPs only contribute a vertical component. The accuracy of both PCP and LCP coordinates allows their use as either control or check points during our investigations. In contrast, the points represented as red triangles in **Figure 3** were just marked on the street and used as additional height check points since their positional accuracy is insufficient for the aspired accuracy level. Point coordinates for the respective signals were provided by geodetic survey, i.e. either GNSS or tacheometric measurement. The accuracy of these reference points is in the range of 1-3 mm. Providing such quality for a considerable number of points scattered in a larger test area requires great effort, while the inevitable remaining errors may already influence the overall accuracy of our investigations.

At the time of our first flights, no UAV platforms were available that combined a lidar system with a dedicated medium-format photogrammetric mapping camera. Thus, for our earlier experiment in March 2019 we used a RIEGL RiCopter octocopter, which combined a RIEGL VUX-1LR lidar sensor with two oblique-looking Sony Alpha 6000 cameras. In the original concept of the platform, these cameras were intended only to provide RGB color values for the respective lidar points. For such applications, the rather large GSD of 1.5-3 cm at a flying height of 50 m above ground and the rather low radiometric quality of the cameras are sufficient. However, this limits the accuracy of the AAT, which is an integral part of the desired hybrid georeferencing approach.

Triggered by the advantages of joint data collection, commercial platforms are now becoming available, which provide both a lidar system and a medium-format photogrammetric camera. One example is the UAV platform of the company Skyability, which integrates the photogrammetric Phase One iXM-RS150F camera with a RIEGL VUX-1UAV laser scanner and a precise Applanix AP 20 GNSS/IMU unit. This system was used for our flight campaign in March 2021.

As shown in **Figure 3**, our test flights comprised 52 longitudinal (i.e. north-south) strips, together with six diagonal strips to cover the steep wooded slope in the south-eastern corner of the area. The extra flight lines with diagonal X-shaped trajectories were captured for further stabilization of lidar data processing. With a flying speed of 4 m/s, a nominal flying altitude of 53 m above ground level, a strip width of 20 m, a pulse repetition rate of 550 kHz, a scan line rate of 80 Hz, and a scanner field-of-view (FoV) of 70°, the resulting mean laser pulse density is 300-400 points/m^2 per strip and about 1300 points/m^2 for the entire flight block due to the nominal side overlap of 50% as well as the diagonal strips. The laser footprint diameter on the ground is less than 3 cm; the ranging accuracy, as reported in the data sheet of the sensor, is 10 mm.

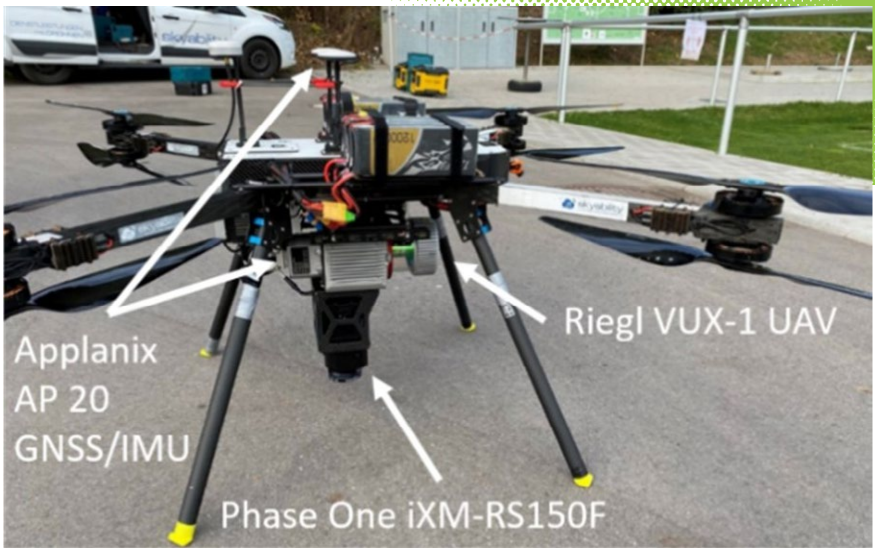


Figure 5: UAV platform with RIEGL VUX-1 UAV scanner, Applanix AP 20 GNSS/IMU unit and Phase One iXM-RS150F camera.

Georeferencing of lidar and image data

During acquisition of lidar data, the measurements of the inertial navigation system and the laser scanner are time-stamped. In post-processing, the IMU and GNSS measurements are combined, using a Kalman filter, into a trajectory, which provides the position and attitude of the platform over time. The polar elements, i.e. ranges and angles, are determined for each laser shot during data acquisition. Based on the trajectory, the scanner's mounting calibration and the polar measurements of the laser scanner, we calculate the 3D coordinates of each detected laser echo by direct georeferencing. Any error in the estimated trajectory, the mounting calibration, i.e. the position and orientation offset between the estimated trajectory and the scanner's own coordinate system, or the scanner's measurements will cause an offset between point clouds of different flight strips in overlapping areas. Respective discrepancies are detected within standard quality control procedures. If the deviations exceed acceptable limits, a typical lidar workflow also includes a strip adjustment to minimize the offsets between the strips. We apply the method presented by Glira et al. (2016), as implemented in the software system OPALS. Within a sophisticated calibration procedure, the six parameters of the mounting calibration (lever arm and boresight misalignment), a global datum shift, as well as trajectory corrections are estimated to minimize the discrepancies defined as point-to-plane distances within the overlap area of pairs of flight strips. To support absolute orientation, the LCPs are additionally considered within this step. Two different solutions for the trajectory correction by the lidar strip adjustment are feasible: (i) the bias correction model considers a constant offset (Δx, Δy, Δz, $\Delta roll$, $\Delta pitch$, Δyaw) applied to the original trajectory solution of each individual strip; or (ii) a spline model can additionally model

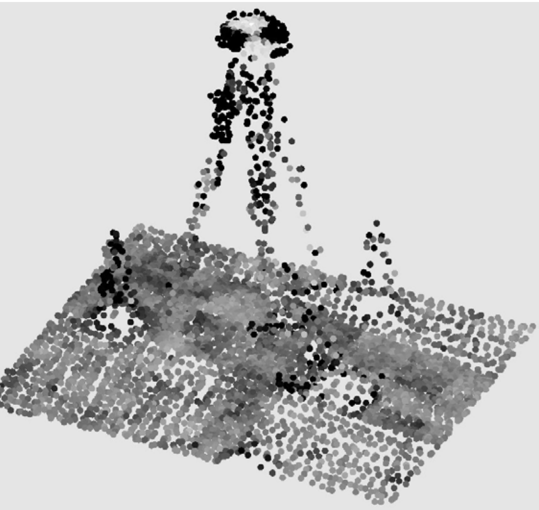


Figure 6: Lidar point cloud at a PCP.

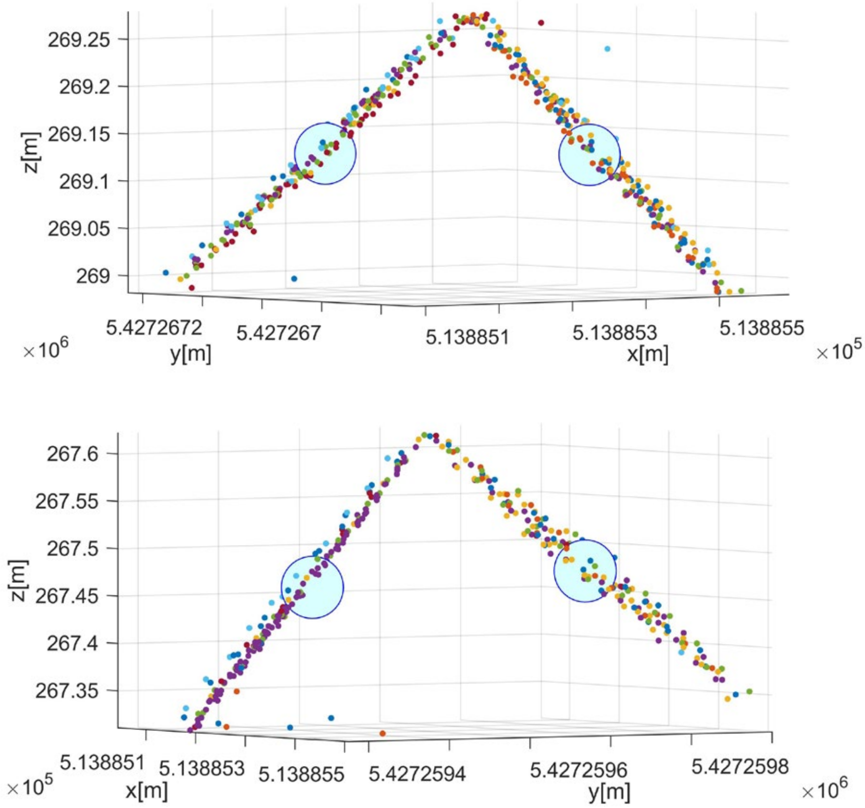


Figure 7: Lidar point cloud for two different LCPs. The center of gravity from the signal is indicated by a blue circle. Lidar point clouds are colored according to the corresponding lidar strip.

time-dependent corrections for each of these six parameters by cubic spline curves. This adds much more flexibility to further minimize the discrepancies between overlapping strips. However, the inherent disadvantage of overfitting by splines can potentially produce block deformations like bending.

Figure 6 depicts a point cloud at a checkerboard target of a photogrammetric control plane (PCP). Since these signals are oriented horizontally, they only provide point-to-plane differences in the vertical direction. For this reason, they are used only as check points for the vertical component during our investigations on lidar georeferencing. In contrast, the two segments of the lidar control plane (LCP) are inclined by 45°. Hence, the respective point-to-plane differences have both vertical and horizontal components. During georeferencing of the lidar block, the LCPs can be used as both control and check points. **Figure 7** shows the lidar point cloud in the vicinity of two LCPs. The respective reference point is depicted in green; the color of the lidar cloud is defined by the respective lidar strip. Each plane of the LCP features an area of 0.32 m^2, which results in about 350 lidar points to compute the best fitting plane estimated from the neighboring points of the lidar strips. In this example, the visual interpretation already shows a good fit between points of different lidar strips. Obviously, the deviation to the point of reference is of the same order as the precision of the lidar range measurements, which is given as 5 mm for the VUX-1 UAV system used. For our flight campaign in March 2021, the standard deviation of the residual deviations for the bias solution was 0.92 cm at the PCPs used as check point information. This corresponds very well to the standard deviation of 0.95 cm for the flight campaign in March 2019.

Hybrid georeferencing by joint orientation of lidar and aerial images

The hybrid georeferencing of lidar and aerial images is an extension of the traditional lidar strip adjustment with additional observations from the AAT of image blocks (Glira et al., 2019). Usually, this bundle block adjustment estimates the respective camera parameters from corresponding pixel coordinates of overlapping images, while the object

Method	Ground Control	Ground Check	Min [cm]	Max [cm]	Mean [cm]	Med [cm]	Std [cm]	Std MAD [cm]	RMSE [cm]
Lidar	2x3 LCP	42 PCP	-1.30	2.70	1.07	0.85	0.92	0.89	1.26
		2x2 LCP	-2.80	4.70	3.40	1.05	3.42	4.97	3.56
Hybrid	9 PCP	33 PCP	-0.80	0.60	0.32	-0.30	0.32	0.30	0.38
		2x5 LCP	-1.00	1.50	0.70	0.10	0.78	0.82	0.78

Table 1: Error measures for the flight March 2019 with Sony Alpha camera integrated to the lidar system.

coordinates of these tie points are a by-product. Within the hybrid orientation approach, tie points' object coordinates from the AAT are re-used to establish correspondences between the lidar and the image block, while the resulting discrepancies are minimized within a global adjustment procedure. In this respect, hybrid orientation adds additional observations and thus constraints to lidar strip adjustments. During hybrid adjustment, both laser scanner and camera can be fully re-calibrated by estimating their interior calibration and mounting parameters (lever arm, boresight angles). Furthermore, systematic measurement errors of the flight trajectory can be corrected individually for each flight strip, by either a constant bias for position and orientation parameters or a spline model for time-dependent corrections. Thus, integrating tie point observations from bundle block adjustment significantly stabilizes the trajectory correction.

Figure 8 gives an example for the photogrammetric tie points in white and the corresponding lidar points, coloured by reflectance. As discussed by Glira et al. (2019), problems in providing correspondences between points from image matching and lidar can occur from their different properties. To guarantee a suitable accuracy we used only tie points observed in at least three images with a maximum reprojection error of three pixels. In general, tie point accuracy is defined by the respective bundle block adjustment, which is influenced by the geometry of the image block and the image quality. This is the reason why fewer points are available for the campaign in March 2019 compared to the campaign in March 2021, shown on the left and right of **Figure 8**, respectively. In March 2019 only the rather low-quality Sony Alpha 6000 camera was available, while in 2021 image collection was performed by the medium-format Phase One camera.

Bundle block adjustment of the Sony Alpha images resulted in differences at

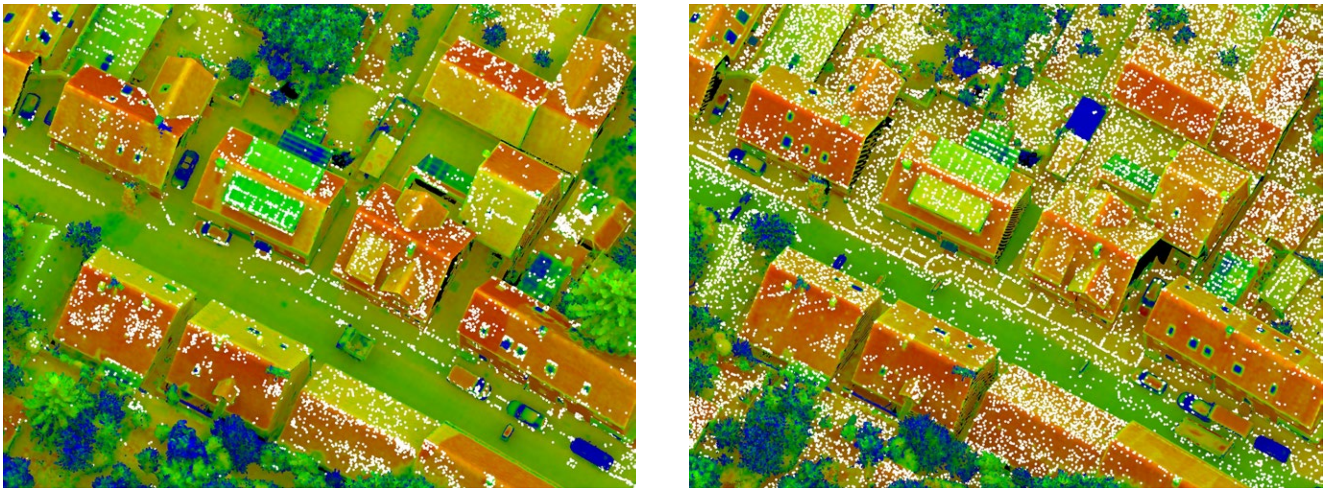


Figure 8: Lidar points coloured by reflectance and photogrammetric tie points (white) for the March 2019 epoch (left) and the March 2021 epoch (right).

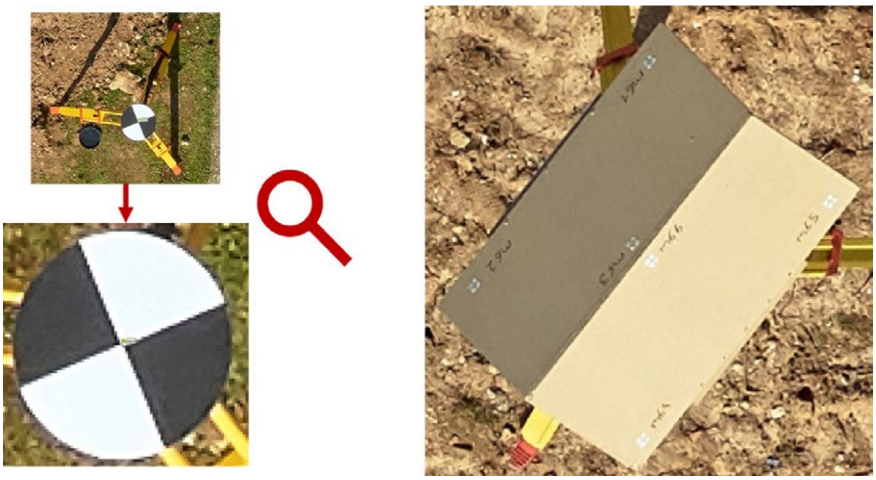


Figure 9: Examples cropped from a Phase One image with PCP and LCP.

independent check points between 5.2 cm (maximum) and 1.2 cm (minimum), with a mean RMSE of 2.5 cm, which was within the range of the GSD of 1.5-3 cm of the captured oblique images. However, the integration of information from that image block into hybrid adjustment resulted in a considerable improvement of the georeferencing results, which is shown in **Table 1**. While the upper part provides accuracy measures for the lidar-only processing, the lower part gives the respective accuracies for hybrid adjustment. The respective accuracy values were computed from point-to-plane differences between georeferenced lidar point cloud and signalized targets, i.e., the PCPs and the LCPs. Since each LCP consists of two planes, i.e. provides two point-to-plane measures, the five LCPs used as check points during hybrid georeferencing provide 2x5 LCP measurements in **Table 1**. With respective differences Δ we compute the mean of absolute difference, the standard deviation, the robust standard deviation, i.e. the Median Absolute and the root mean square error. As is visible, accuracy values of hybrid adjustment could be improved by a factor of three compared to lidar strip adjustment.

Despite these promising results based on the Sony Alpha imagery, their validity is limited by the relatively small number of signalized points used as check point information. For hybrid georeferencing 33 horizontally oriented PCPs were available to check for vertical accuracies of the georeferenced point cloud, whereas vertical and horizontal differences, as provided by the LCPs, were limited to five signals. In combination with the availability of an improved camera system, this was our motivation for the additional test flight in March 2021.

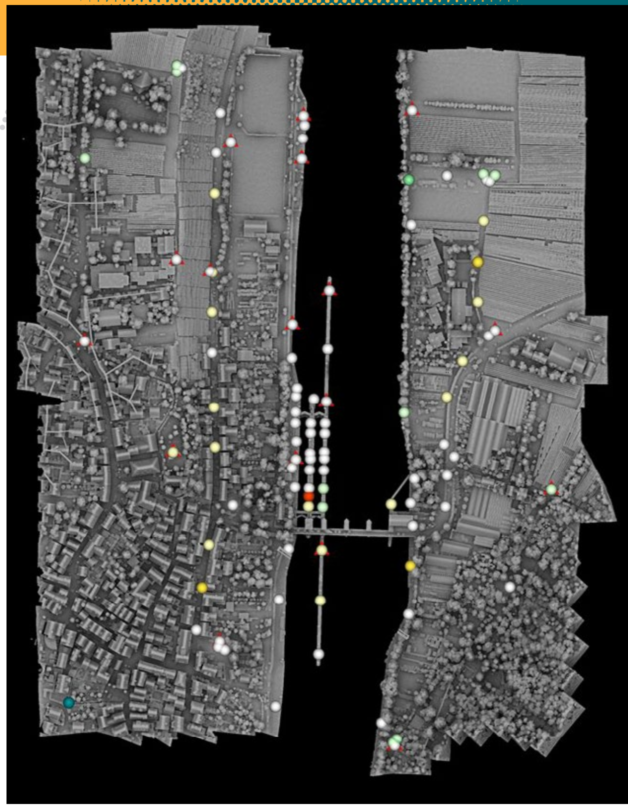
Example images of a PCP and LCP as captured by the Phase One iXM-RS150 camera during our flight campaign in March 2021 are given in **Figure 9**. The 50 mm optics and the selected flying height above ground of 53 m result in a GSD of around 4 mm.

Figure 10 shows the distribution of check and control points in the extended test area as well as the

Method	Ground Control	Ground Check	Min [cm]	Max [cm]	Mean [cm]	Med [cm]	Std [cm]	Std MAD [cm]	RMSE [cm]
Lidar	2x9 LCP	64 PCP	-3.10	1.90	0.76	-0.20	0.95	0.82	0.99
		0 LCP	-	-	-	-	-	-	-
		23 HCP	-3.00	0.30	1.74	-1.50	0.81	1.04	1.90
Hybrid	17 PCP	47 PCP	-2.00	2.20	0.36	0.00	0.58	0.30	0.58
		2x9 LCP	-0.10	1.20	0.60	0.75	0.36	0.22	0.69
		23 HCP	-1.10	1.20	0.52	-0.50	0.45	0.30	0.61

Table 2: Error measures for the flight March 2021 with Phase One camera integrated to the lidar system

color-coded differences between the georeferenced lidar point cloud and the signalized targets. **Table 2** summarizes the respective accuracy measures at the photogrammetric targets (PCPs) and lidar targets (LCP). Profile points signalized on the streets provided additional differences in vertical direction as height check points (HCPs). The upper part of **Table 2** gives the results for the standard lidar-only processing, whereas the lower part summarizes the results for hybrid georeferencing. For hybrid georeferencing, the RMS error is 5.8 mm for the vertical component at the PCPs and 6.9 mm for the inclined LCPs. As for the precision, the more robust values are 3.0 mm for the vertical component and 2.2 mm for the inclined surfaces. These results confirm and improve our earlier results presented in **Table 1**. Obviously, the use of a medium-format photogrammetric camera increases the accuracy of hybrid georeferencing. For the March 2019 flight, we evaluated 4550 images at a GSD of 2.3 cm and lidar points at a density of 989 pts/m^2 measured with a lidar range accuracy of 15 mm during hybrid georeferencing. The corresponding numbers for the March 2021 flight are 3754 images at a GSD of 5 mm with lidar density of 1368 pts/m^2 measured with 10 mm range accuracy. In principle, the increased image resolution for the March 2021 flight should improve the accuracy of hybrid georeferencing even more compared to the March 2019 result. Compared to that flight, we increased the number of signalized check points to improve the overall coverage of our test site. During the evaluation of the 2021 flight, we noticed some larger deviations at those additional points signalized on tripods. However, we kept them in



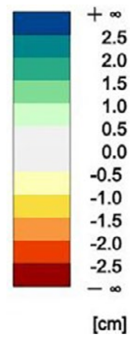


Figure 10: Colour coded differences between georeferenced lidar point cloud and signalized targets for the flight March 2021. Checkerboards used as GCPs are marked by red triangles.

our overall accuracy considerations, despite the fact that this could result in too pessimistic numbers.

In this context, it should be noted that the coordinate accuracy of the signalized points is already of the order of the accuracy of our hybrid georeferencing. These coordinates are provided from terrestrial measurement, i.e. static GNSS or tacheometry for the horizontal and levelling for the vertical component. Thus, hybrid georeferencing provides lidar point clouds from UAV platforms at accuracies which so far were only available from terrestrial measurement.

Deformation monitoring based on different epochs

The ship lock and the surrounding area of Hessigheim which has been covered by our test flights is subject to potential subsidence, caused by the geological structure underground (Kauther and Schulze, 2015). The temporal behavior and magnitude of this deformation process are determined by the responsible authority twice a year. This classical monitoring application is based on large-scale tacheometric and high-precision leveling measurements. By these means, significant deformations of the order of about 10 mm/year were identified at several locations in the past. Although these pointwise terrestrial measurement techniques proved to be highly accurate and reliable, the data collection often causes great effort and financial burden. In particular, the necessity of large-scale monitoring of the area surrounding the ship lock represents one of the key cost factors in this context. Besides economic issues, a pointwise monitoring strategy always carries the risk that small-scale deformations are not captured by the network of monitoring points. To come up with an alternative to such a pointwise monitoring strategy, the German Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde, BfG) as the responsible authority funded our research on area-covering UAV-based data collection.

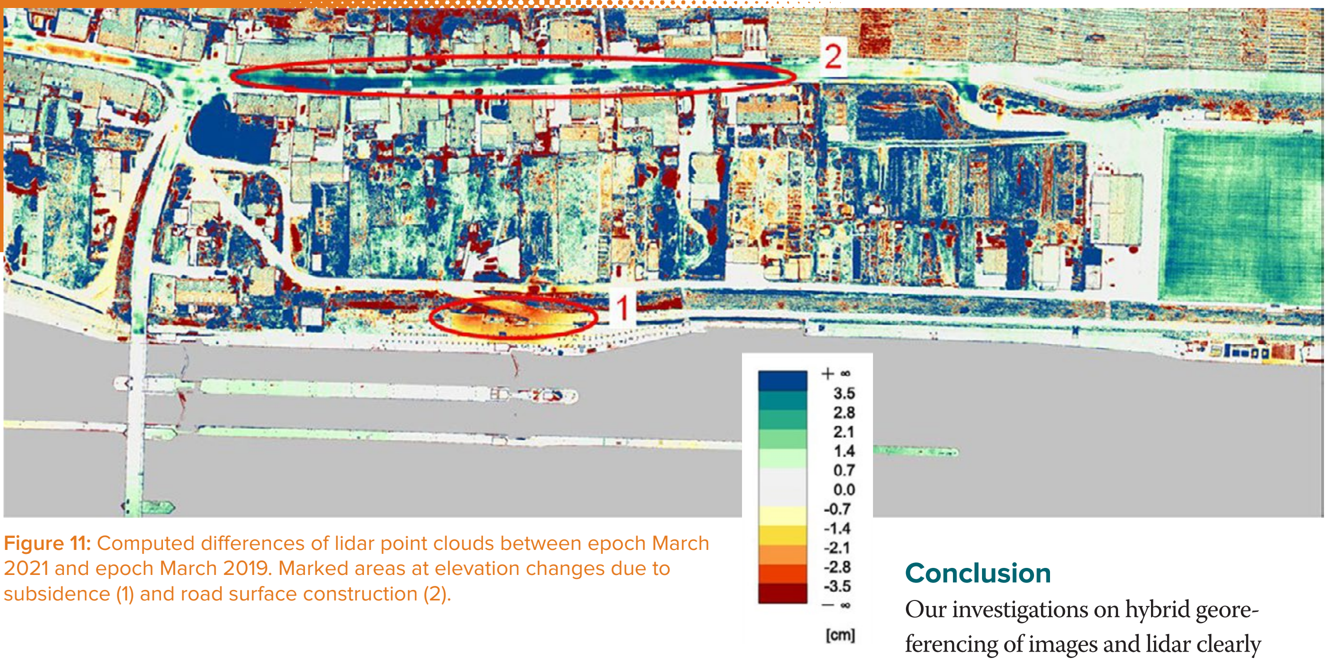


Figure 11: Computed differences of lidar point clouds between epoch March 2021 and epoch March 2019. Marked areas at elevation changes due to subsidence (1) and road surface construction (2).

Figure 11 depicts the computed differences between the point clouds from the measurement campaign in March 2021 and epoch March 2019. The marked area (1) in the immediate vicinity of the ship lock shows differences due to geological subsidence. These could be verified based on prior knowledge of the deformation processes, taken from the terrestrial in-situ measurements. The detected elevation changes at area (2) are due to construction and maintenance work of the road surfaces in the village of Hessigheim. These were performed in summer 2020, i.e. between our measured epochs. One main advantage of airborne lidar is its capability for vegetation penetration, i.e. through trees. However, measurements in low vegetation such as grass result in a mixed signal, i.e. are influenced by the current grass height. Obviously, this is the reason for the elevation differences at vegetated areas visible in **Figure 11**. In contrast to stable street areas, slight elevation differences are also visible at building roofs. These differences at the inclined roof areas result from remaining georeferencing errors for the horizontal coordinates of the respective 3D point cloud. We assume that these errors mainly occur at the measurement campaign in March 2019, when the accuracy of hybrid georeferencing was limited by the comparably low quality of the Sony Alpha images.

Nevertheless, our results demonstrate the potential of UAV-based data collection to monitor the occurring displacement rates of 6-10 mm/year by applying a suitable sensor setup and hybrid georeferencing. Smaller deformations in the range of only 1 to 2 mm, however, are still beyond detectability. Since such height changes can already be of particular interest, UAV-based monitoring will be integrated with classical and well-established geodetic surveys in future projects. These will apply annual flight missions to detect deformations over larger areas, followed by a more targeted initiation of expensive terrestrial in-situ measurements.

Conclusion

Our investigations on hybrid georeferencing of images and lidar clearly demonstrate the potential of UAV-based data collection to provide dense 3D point clouds at sub-centimeter accuracy. Compared to lidar-only processing, hybrid georeferencing improved the vertical accuracy (RMS) from 9.9 mm to 5.9 mm for our March 2021 flight and from 1.26 cm to 3.8 mm for the March 2019 flight. This enables applications like deformation monitoring, which up to now were feasible only with terrestrial geodetic engineering techniques. In principle, separate platforms can be applied to collect lidar and image data in order to simplify data collection by small and lightweight UAV systems. However, our investigations proved the advantage of joint data collection from a single platform, which constrains the georeferencing process to a joint trajectory for both sensors. Furthermore, contemporaneous data collection simplifies the required matching between lidar measures and tie points from AAT as the most important prerequisite for hybrid georeferencing. Since hybrid adjustment jointly aligns the lidar and image block, ground control can be limited to standard photogrammetric signals, while dedicated lidar control planes are no longer required. This is considered as another main advantage of the hybrid adjustment, as time-consuming terrestrial measurements can be reduced. These benefits were already demonstrated by our first investigations, which applied relatively simple Sony Alpha cameras viewing obliquely. However, the full potential of hybrid georeferencing could be proved using high-quality nadir images as captured by a photogrammetric Phase One camera. Our configuration captured imagery at a GSD of approximately 4 mm, which resulted in lidar georeferencing accuracies of 5.9 mm RMS by hybrid georeferencing.

In addition to high geometric accuracy of the respective point clouds, hybrid adjustment also provides precise co-registration of image and lidar data. This is for example required if MVS is supported by additional lidar measures to enhance the 3D reconstruction process. Such photogrammetric software systems typically generate 3D meshes as an alternative representation to unordered set of 3D points. These meshes are graphs consisting of vertices, edges, and faces that provide explicit adjacency information. The main differences between meshes and point clouds are the availability of high-resolution textures and the reduced number of entities, which is for example beneficial for visualization. Furthermore, 3D meshes are very suitable to integrate information from both lidar and imagery, which is an important advantage both for geometric and semantic information extraction. As an example, semantic segmentation considerably benefits if both lidar echo characteristics and high-resolution imagery are available during feature extraction. This was our motivation to provide the 3D point clouds and meshes as captured during our project in Hessigheim for a benchmark on semantic segmentation (Kölle et. al., 2021). This benchmark includes our multi-temporal lidar point cloud and 3D mesh data sets which have been labelled into 11 classes in order to allow interested researchers to test their own methods and algorithms on semantic segmentation for geospatial applications. From our point of view, such applications will considerably increase the demand for joint collection of airborne lidar and imagery and thus the need for hybrid georeferencing as an important processing step.

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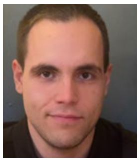


Michael Kölle holds a MSc in geodesy and geoinformatics from the University of Stuttgart. As a member of the geoinformatics group at ifp, he is currently working on his PhD. His main research interests focus on combining paid crowdsourcing and machine-learning techniques such as Active Learning for generating high-quality training data, especially in the context of 3D point clouds.

Michael Cramer is a senior lecturer at ifp. He has many years of experience in the field of sensor georeferencing and photogrammetric sensors. In addition he serves as secretary of the German Society of Photogrammetry, Remote Sensing and Geoinformation (DGPF).

100 YEARS of Innovation in Heerbrugg

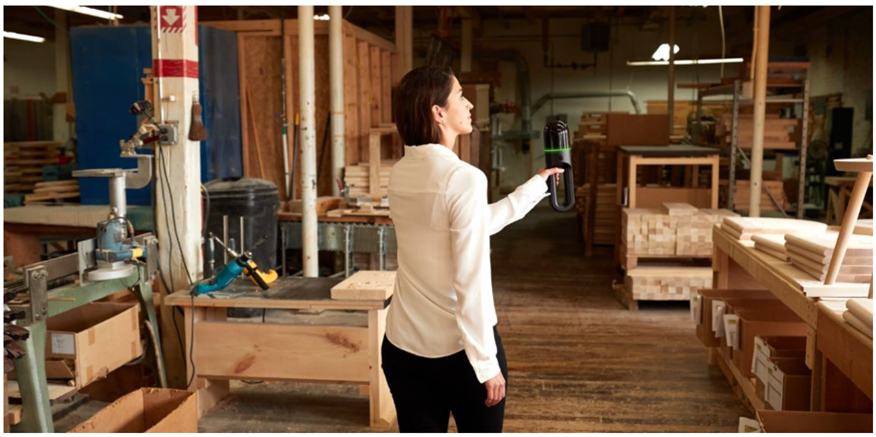
Heinrich Wild's company was founded in 1921

The company "Heinrich Wild, Werkstätte für Feinmechanik und Optik" was founded in Heerbrugg, Switzerland, on April 26, 1921. Over the decades, this company developed into the world-renowned Leica Geosystems AG, an essential component of the Hexagon technology group. Founder and master innovator Heinrich Wild revolutionized surveying with smaller, more practical, yet more accurate instruments. Heerbrugg has repeatedly been the source of major innovations, such as the first optoelectronic distance meter in 1968; the first electronic theodolite with digital data recording in 1977; the first surveying system based on GPS signals in 1984; the first digital level in 1990; the first hand-held laser distance meter in 1993; the first airborne digital image sensor in 2000; and the smallest, lightest and most user-friendly laser scanner in 2019. What was the recipe for success in this hundred-year history of innovation?

A difficult start

The structural crisis in the embroidery industry in the early 1920s hit eastern Switzerland and especially the Rhine Valley so hard that its impact in the region exceeded that of the global economic crisis ten years later. Because the major Rhine-regulation projects were coming to an end at the same time, new employment was urgently needed for the people of the Rhine Valley.

After working for the Swiss Federal Office of Topography[1], Heinrich Wild had built up the geodetic department as chief engineer of the Zeiss-Werke in Jena, Germany. He already had a reputation as a brilliant inventor in the surveying world. Because of the uncertain future after the Great War and the constant devaluation of money, he wanted to return to Switzerland with his family. With design plans of geodetic and photogrammetric instruments in mind, he looked for partners in Switzerland to found an optical precision-mechanical experimental workshop. He remembered his fellow officer Dr. Robert Helbling in Flums: the owner of a well-known surveying office would be very good at assessing the market needs. Helbling knew Jacob Schmidheiny, an industrialist from the Rhine Valley, from their time studying together at the ETH[2]. Schmidheiny took a liking to the project. As a successful entrepreneur, he had the right sense of purpose and the necessary

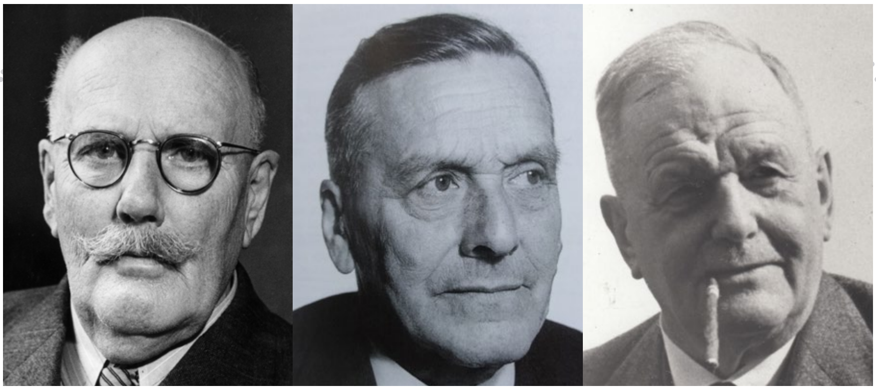


The BLK2GO hand-held laser-imaging scanner digitises space in 3D while you move.

BY EUGEN VOIT

1 Swiss national mapping agency, now also branded as swisstopo.

2 Eidgenössische Technische Hochschule Zürich



Left: Heinrich Wild 1877–1951, the inventor. Middle: Jacob Schmidheiny 1875–1955, the financier. Right: Dr. Robert Helbling 1874–1954, the practitioner.

money. Heinrich Wild repeatedly pointed out that precision-mechanics specialists would be available in the area of the watch industry in Switzerland's western cantons. But Schmidheiny's guiding principle was clear from the start: he wanted to create jobs for people in the Rhine Valley.

On April 26, 1921, the three signed a contract to found a simple company under the name "Heinrich Wild, Workshop for Precision Engineering and Optics, Heerbrugg." The production of Heinrich Wild's new level began, but many of his innovative ideas and designs were not yet technically mature in 1921. After a year—even before the first instruments had gone on sale—the company's capital was exhausted. In 1923, the company received an injection of new capital through the foundation of the "Verkaufs-Aktiengesellschaft Heinrich Wilds Geodätische Instrumente Heerbrugg" (Heinrich Wild's Heerbrugg Selling Company for Geodetic Instruments). On a commission basis, this joint stock company provided credit and obtained orders for products. However, because of technical problems in productization coupled with a shortage of optical and precision-mechanics specialists, Heinrich Wild's vision of a small, compact universal theodolite proved difficult to realize: in 1924, only 27 of the planned 350 T2 theodolites were completed. Not until 1929 was the company on safe ground and able to pay out a dividend for the first time.

Heinrich Wild's inventions also laid the groundwork for photogrammetry. This made it possible to produce accurate maps economically, such as the then-new Swiss national map. WILD's phototheodolites, Autograph stereoplotters and aerial cameras quickly became reputable worldwide.

The test workshop becomes a company

The streamlining of the organization and the establishment of a worldwide sales network by the new director Dr. Albert Schmidheini brought about a first expansion phase with 250 employees in 1930. The 1930s economic crisis interrupted the expansion: in 1933 130 employees remained.

The increasingly threatening political situation in the 1930s triggered a need for military instruments in Switzerland too. In record time, prototypes of telemeters, telescopic sights, omnidirectional telescopes and instruments for artillery units were developed, built and demonstrated in Bern. As a result of this successful activity, WILD became one of the main suppliers to the Swiss Army, and expansion began again in Heerbru

During its second growth phase between 1936 and 1941, the workforc increased to more than 1000. It remained at that level until 1951 and then continued to rise steeply, exceeding the 3000-mark in October 1961.

The inventive genius leaves the growing company

Around 1930, Heinrich Wild and his family moved from Heerbrugg to Zürich. He rarely came to the Rhine Valley anymore, and communication became increasingly difficult. In 1933, he left the company and went into business for himself as an inventor and designer. Heerbrugg continued to commission him until 1935, when he signed a contract with Kern & Co in Aarau. He remained loyal to Kern until he passed

The first C2 aerial camera was delivered to the Swiss Federal Office of Topography in 1927.

The apprenticeship department of WILD in 1930.

away in 1951. However, the name "Wild" remained omnipresent in the company name and product names until 1990, when the Leica era began. For many people of the Rhine Valley, "Wild" is still synonymous with the Heerbrugg factory.

Skilled workers in short supply

Recruiting personnel from the optical centres of the time helped counter the acute shortage of skilled workers in the optical and precision-mechanics sector, but the goal was to recruit and train Rheintalers. As early as 1921, two apprentices selected personally by Heinrich Wild began their apprenticeship in Lustenau. A dedicated school was founded in 1924 to provide even more targeted training. In 1930 this became the Fachschule für Feinmechaniker und Optiker, the Technical School for Precision Mechanics and Opticians.

The culmination of the precision-engineering epoch

In 1943, WILD drawing instruments were brought onto the market. The impulse for this was not least the Kern DKM1 theodolite, which bore the inscription "Construction Dr. H. Wild" despite protests from Heerbrugg. The T4 astronomical theodolite was the pinnacle of optomechanical precision when it was launched in 1944. This instrument enabled a direct reading of 0.1" with an accuracy of ±0.3"—still legendary today.

WILD also collaborated with international research partners. In 1952, for example, the BC-4 ballistic camera—developed together with the Ballistic Research Center in the USA—went into production. This camera combined the high angular-measuring accuracy of the T4 with the high-resolution capacity of the special aerial-imaging lenses. The BC-4 camera would later also be used for satellite triangulation and thus for constructing the first global positioning system.

Optical flights of fancy

In 1947, WILD continued its pioneering work in the field of microscopy. The first research microscopes produced in series in Switzerland, the M9 and M10, had their market launch. Hans A. Traber—who later became famous for his natural-history program on Swiss radio and television—joined Heerbrugg in 1947 and headed the Microscopy Department from 1949 until 1956.

Thanks to management's vision and WILD's reputation as an employer, the company succeeded in attracting top-class specialists to the Rhine Valley. In February 1946, Ludwig Bertele joined Heerbrugg as Head of Optics Development. The former specialist for the design of photo lenses at Zeiss-Ikon in Dresden was probably the most important optics designer of the time. He was entrusted with the development of a new type of high-performance lens for aerial photography. Under his leadership, the optical design office for the first time used an electrical calculation device to design and optimize the lenses. The device they used, the Zuse Z22, was one of the first "computers" to be produced in series. WILD was the first Swiss industrial company to purchase such a system. With this electronic calculator, it was possible to calculate about 3000 refractive or reflective surfaces per day. Using traditional mechanical calculators, two experienced employees would have spent 20 working days to complete the same task.

On the night of July 21, 1969, people worldwide sat with bated breath in front of their television sets as the first humans, astronauts Neil Armstrong and Buzz Aldrin, set foot on the moon during the Apollo 11 mission. NASA made use of various instruments from Heerbrugg in its lunar landing program. The T3 was used in the orientation of the Inertial Guidance System and the T2 for the optical alignment of the LEM lunar module during construction. During the television broadcast of the spectacular moon flight, an astronaut could be seen on screen carrying out positional measurements. WILD had supplied the lens system of the instrument he used.

The age of electronics begins—with a cooperation

In 1958, an electronics department was set up in Heerbrugg. At the

A8 Autograph stereoplotters in operation.

10th Congress of the Fédération Internationale des Géomètres (FIG) 1962 in Vienna, the first microwave distance meter was presented: developed in cooperation with the electronics company Albiswerk Zurich, the Distomat DI50 was the world's first electronic distance meter, with a measuring range of 100 m to 50 km. Radically new technologies were often brought into the company via cooperations or acquisitions. In 1963, a Distomat DI50 cost around 40 times the monthly salary of a surveyor. Radically new technologies are often costly initially and therefore only economical for very specialized applications.

The new premier discipline—optoelectronics

The first infrared distance meter, the DISTOMAT DI10, was a joint development with the French company Sercel (Société d'Etudes, Recherches et Constructions Electroniques) in Nantes, and was launched in 1968. This first close-range distance meter revolutionized surveying technology. It did not yet use a laser, but instead the infrared radiation of a gallium arsenide diode. It marked the beginning of optoelectronics, which became a core competency in Heerbrugg. At the 14th FIG Congress in Washington in 1973, there was a great deal of interest in the new DI3 infrared distance meter. It became a geodesy best-seller, and the name DISTOMAT became synonymous with distance meters.

A Volkswagen from Heerbrugg

In the 1970s, analogue photogrammetry reached its peak. By 1975, 1000 A8 Autographs had left the Heerbrugg factory. The A8 was often referred to as the "Volkswagen of photogrammetry." But technological developments, and digitalization in particular, ultimately brought the Autograph business to a standstill. Image processing and computer science became the new premier disciplines for the digital photogrammetry that followed.

Innovation requires technical excellence in new disciplines

An intensive exchange with universities was an essential motor for innovation. Dr Hugo Kasper, previously a professor of geodesy at the Technical University in Brno, joined WILD in 1948 and took over the newly formed Research and Development Department for Photogrammetry. The A7 and A8 Autographs and the B8 Aviograph were developed under his leadership. In 1961 he was appointed professor of geodesy, especially photogrammetry, at ETH. He remained in contact with WILD until his retirement in 1973. In 1955, Hans Tiziani completed his apprenticeship in optics and mechanics at WILD. After training as a technician and qualifying as a mechanical engineer, he studied optics at the Sorbonne and the Paris School of Optics. He graduated as an engineer in 1963 and received his doctorate from Imperial College London in 1967. From 1968 to 1973, he was responsible for establishing and managing the Optics Group in the Department of Technical Physics at ETH. From 1973

To measure a distance between 100 m and 50 km, a DI50 was set up at each end-point and the distance calculated by measuring the transit time of the microwave radiation. The picture shows a DI50 being used in Mexico.

to 1978, he was head of WILD's central laboratory. In 1978, he was appointed to the University of Stuttgart and led the Institute of Technical Optics until his retirement in 2002. To this day, he remains in intensive contact with "his" company in Heerbrugg.

Max Kreis, a graduate in mechanical engineering from ETH, joined the Heerbrugg design office in 1932. Throughout his professional career, he was a strong advocate of higher education. As president of the executive board, in 1968, he was a founding member of the Institute of Technology in Buchs (NTB), which today is part of the Eastern Switzerland University of Applied Sciences. Dr. Albert Semadeni, later president of the board, initiated the construction of a cantonal school in Heerbrugg by tabling a motion when he was a member of the St. Gallen Cantonal Council. The school opened in 1975.

Surveying 4.0 begins in 1977

The fully automatic electronic infrared tachymeter TC1 was presented at the 15th FIG Congress in Stockholm in 1977. Electronics took over the measurement of the distance and the angles as well as the logging of the measured values. A cassette was used for data storage. This marked the beginning of the era of computer science in surveying. In the beginning, however, digitalization was a bulky and weighty affair. For the first time ever, in 1980, the GEOMAP system enabled continuous data flow from geodetic field measurement to the finished graphical plan using the interactive graphical workplace-computer Tektronix 4054.

In December 1984, the WM Satellite Survey Company was established as a joint venture with the Magnavox Government and Industrial Electronics

The Wild TC1 was a fully auto-matic tachymeter with a cassette recorder for digital data storage.

The original DISTO of 1993—still weighing 900 g and rather expensive.

Company in Torrance, California. The new GPS surveying system WM101 was presented as early as May of the following year, marking the beginning of the GNSS success story that continues to this day.

Wild Heerbrugg—Wild-Leitz—Leica—Leica Geosystems

The period between 1988 and 2000 was eventful in terms of company names, composition and ownership. The acquisition of Kern in Aarau brought a bundle of industrial-measurement technology to Heerbrugg, and today this still represents an important market segment within the Hexagon Group.

Crazy ideas sometimes become successful products

In 1990, the NA2000—the world's first digital level—attracted a great deal of attention at the most important surveying congress in the USA in Denver. It was awarded the innovation prize in photonics. The device's real magic is in its associated algorithm: industrial mathematicians optimized the evaluation algorithm that worked on a PC so that it also delivered good results on a field device in an acceptable time.

The idea of launching a more accurate alternative to the ultrasonic devices and steel measuring tapes available on the market, based on all the experience with high-quality add-on distance meters, was greeted internally with a tired smile. In the end, however, the DISTO, the world's first hand-held laser distance meter, set new standards. When it was presented in 1993 at the international construction fair BATIMAT in Paris, this new development created a real stir and received a prize for innovation.

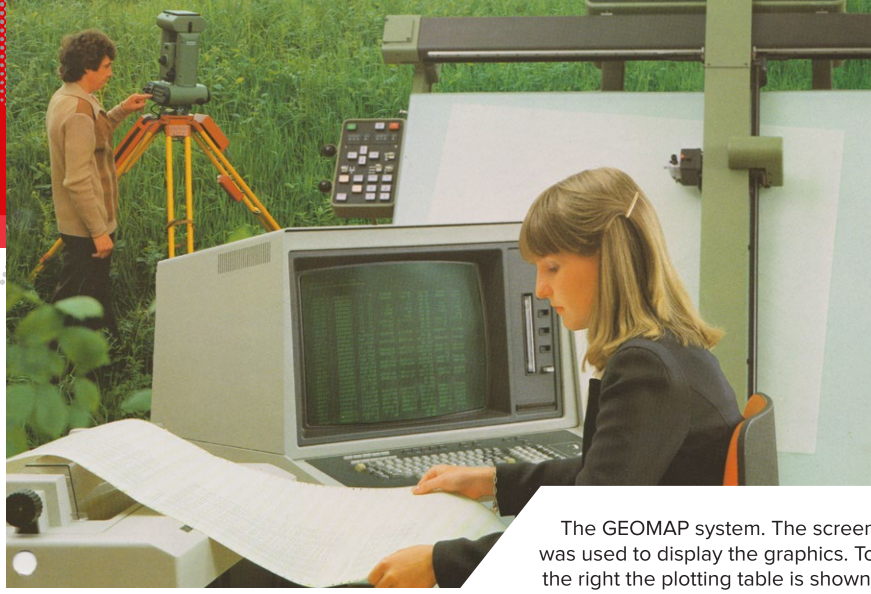
Everything is digital—workflow and stock-market launch

The first digital aerial camera, the ADS40—developed jointly with the Institute for Optical Sensor Systems of the DLR[3] (German Aerospace Center)—was presented in 2000. The sensor's success was mainly due to a robust workflow, which required effective, frictionless processing of the massive amounts of data generated during flight operations. Software innovation was the key to this.

Acquiring the Californian company Cyra Technologies in 2000, Leica Geosystems was the first surveying company to invest in laser scanning. This technology was quickly internalized and developed further in Heerbrugg. Under the slogan "High Definition Surveying," the next-generation laser scanner HDS3000 was presented alongside the new Cyclone 5.0 software.

3 Deutsches Zentrum für Luft- und Raumfahrt.

In 2006, not only the development but also the production of the scanners was concentrated in Heerbrugg.



The GEOMAP system. The screen was used to display the graphics. To the right the plotting table is shown.

Stronger together—sensor fusion

Acquisitions complemented the company's own innovation activities as it expanded its solutions. This trend was further accelerated by the acquisition of Leica Geosystems by the Swedish technology group Hexagon AB in 2005.

In the past ten years, the acquisition of nearly 40 companies strengthened the company's presence in emerging markets and supported its expansion into new markets. In 2013, for example, the acquisition of Italy's Geosoft laid the foundation for the Pegasus mobile mapping product line, which records images and lidar data in a GIS-enabled platform while in motion, thus enabling complete capture of the surrounding area. The acquisition of the Berlin company Technet in 2015 added GIS software solutions for railway applications to the Pegasus product line. Acquiring Italy-based IDS GeoRadar in 2016, the company obtained extremely competitive radar solutions, such as ground-penetrating radar systems that can precisely detect nonvisible underground pipes and cavities. In combination with Pegasus, recorded underground infrastructure can be linked to the spatial data recorded above ground.

CityMapper, the world's first "fused sensor" for aerial photography, with newly developed cameras and laser sensors, was introduced in 2016. It consisted of an RCD30 multispectral camera in the center, four oblique RCD30 cameras angled at 45° and a Hyperion lidar unit. It was specially designed for challenging 3D city views and formed part of the RealCity overall solution for 3D city model creation.

In 2017, the first GNSS with true tilt compensation was introduced. The GS18 T was the world's fastest and easiest-to-use GNSS RTK rover. Now, professionals could measure points more quickly and more easily, as they no longer had to hold the pole vertically. The development of a robust tilt compensator had been an R&D target for decades. The solution was an IMU (inertial measurement unit) integrated into the GNSS antenna. The IMU recorded acceleration and rotation values and offset them against the GNSS position data.

On the occasion of Leica Geosystems' stock-market launch in 2000, the Zurich stock exchange was transformed into a point cloud using a Cyrax 2500.

Smaller, lighter, simpler and mobile

On November 18, 2016, CTO Burkhard Boeckem presented the BLK360 to the public at Autodesk University 2016. The timelessly elegant laser scanner with its compact design, weighing only 1.1 kg, was the smallest, lightest and most powerful device on the market. The BLK360 won countless design and innovation awards. A dedicated team brought this product to market in a surprisingly short time using the latest development methods.

The first hand-held imaging laser scanner BLK2GO was presented at HxGN LIVE 2019. In real-time, as the user moves, it digitizes rooms in 3D using images and point clouds. The integrated SLAM technology (simultaneous localization and mapping) enables the precise determination of the movement path while simultaneously capturing the space's geometry. And, once again, the spirit of Heinrich Wild beckons—"small, light and mobile" like the T2.

In addition to surveying-related applications, the BLK2GO is also increasingly used in other areas, including forensics, the film industry and archaeology—thus considerably expanding its market.

100 years and still raring to go

Hexagon's Geosystems division will continue to innovate in its five core industries: surveying, construction, heavy-machine control, mining and geospatial solutions. But the range of possible applications for new and emerging technologies also opens new markets: mobile 3D scanning technology and software solutions allow investigators to preserve digital copies of crime or crash scenes but also enable new insights for architectural scientists and archeologists. Lasers, GNSS receivers and total stations enable media and entertainment professionals to create digital replicas of real-world objects or environments to incorporate into movies and games; urban planners use the same technology to model city development. Easy-to-use monitoring solutions can help professionals screen for natural hazards, facilitate building maintenance or assist in monitoring assets in the railway industry—to name but a few examples.

Hexagon invests between 10% and 12% of its turnover into research and development each year. Successful innovation, however, also requires the necessary corporate culture. Ever since the company was founded in 1921, it has always remained important to mix the good local conditions with new ideas brought in from outside. The diversity that results from Heerbrugg's multinational workforce—with people hailing from 50 countries—enables and promotes a culture of innovation.

For its next chapter, Hexagon is committed to bringing this inventiveness to bear on developing innovative technology that drives sustainability by improving efficiency, increasing safety and reducing waste. By incorporating sustainability aspects in its innovation process, Hexagon seeks lower carbon dioxide emissions and combats climate change while helping existing and new customers tackle their challenges more quickly, easily and efficiently.

Eugen Voit, a physicist from ETH, held various R&D management positions within Leica Geosystems, part of Hexagon, for 30 years before retiring in 2018. As a member of the workgroup "Historic WILD," he is dedicated to the preservation and documentation of the company's history.

Book Review, *continued from page 48*

developments," and wisely provides a valuable summary of the state of the art while refraining from predictions. In both chapters 8 and 9, the authors mention some of the companies and organizations involved in acquiring, processing and disseminating imagery and touch on the mergers and acquisitions that lie behind some of them. There is welcome coverage of policy issues too. Perhaps the book would have benefited from even more discussion of business questions, such as the effect of free-to-download imagery that some government suppliers provide on the economics of commercial imagery from both large and small suppliers; the dependence of profitability on large infusions of revenue from government defense agencies; and the changing nature of the customer base. Some readers would conceivably benefit from advice on when to use images acquired from satellites, as opposed to aircraft, UAVs or ground vehicles—today we have an embarrassment of riches and the decisions become more complex as the resolution of satellite imagery increases.

This is undoubtedly a useful synthesis. Readers will be grateful for a source so up to date—at least until things change! The authors have done well to compress a wealth of material into a volume of reasonable size. The price is not unreasonable as modern textbooks go and the publisher has not been grudging in using color wherever it enhances the graphics. Nevertheless, your reviewer found innumerable small mistakes, not just typos, but incorrect cross-references to sub-sections and figures, many of which were presumably caused by insufficient checks on changes necessitated by the update from the first edition. The three German authors are completely fluent in spoken and written English, but many sentences have slipped through which, while correct *sensu stricto*, include mechanical, unnatural expressions in English. Your reviewer was left with the feeling that, in the rush to publish, a final check by a meticulous sub-editor did not take place. There are also some technical errors, such as referring to CE90 as a measure of elevation accuracy. Some initialisms and acronyms are not in the list at the beginning of the book. The result is a disappointing quota of irritants—unusual from this highly competent publisher with a strong track record in geospatial offerings. Nevertheless, the book is attractive and *LIDAR Magazine* readers with more than a passing interest in the extraction of geographic information from space imagery would do well to read it.

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.

BY STEWART WALKER

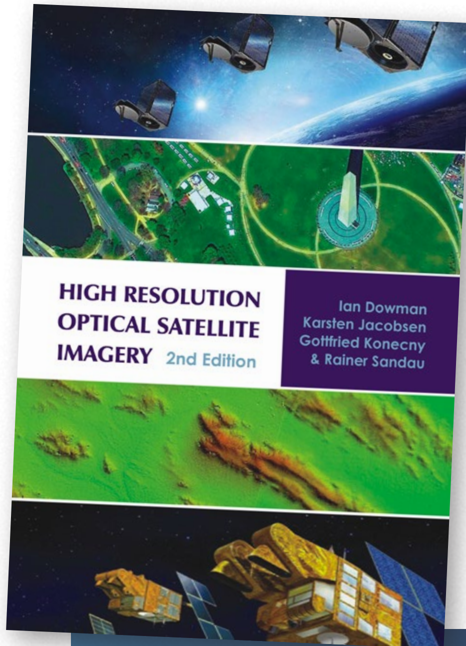
High Resolution Optical Satellite Imagery

This is a major update of a volume first published in 2011. The authors are all renowned—giants, indeed, of our profession—and your reviewer ought to reveal that he knows each of them well. All four have immense experience of researching and working with satellite imagery.

The authors set out their stall early. They start with the ASTER sensor and define "high resolution" as ground sample distance of 16 m or less. They eschew Landsat to some extent on the grounds that the imagery is typically not used photogrammetrically. Later on they further separate out very high resolution (GSD <2 m). The book does not cover lidar or radar, which are hardly "optical imagery", though both ICESat-2 and IfSAR are mentioned, the latter, however, without acknowledgement of the new constellations that are becoming operational.

The book has nine chapters. After an introduction by Dowman, Konecny takes us on a whistlestop, rather idiosyncratic history of satellite imagery—a delightful, engaging read from someone who was involved in the photogrammetric treatment of space images from the very beginning.

Then we come to the entrée. Chapter 3, "Principles of high resolution optical sensors," by Sandau, shows the author deep in his comfort zone. Moreover, he places many of the principles he introduces in the context of topographic mapping. The material is essential to a full understanding of the acquisition of optical imagery from space, but is intense in places and readers would benefit from going through it more than once. The next two chapters, however, are more descriptive than analytical: "Sensors with a GSD of greater than 2 m up to 16 m" (Jacobsen and Dowman) and "Sensors with a GSD of 2 m or less". These are useful, but the short accounts of a large number of satellites constellations and the sensors they carry are not only a little daunting, but also the part of the book that will most rapidly become outdated. Jacobsen, in turn, is embedded in his own specialist area in the excellent chapter 6, "Calibration, sensor models and orientation." Many of us have admired his presentations and publications in this area and, happily, the chapter is long enough to go into some detail. Jacobsen is also responsible for chapter 7, "Processing and products," which is equally masterly. He covers a considerable breadth of material, yet there is enough detail to hold the reader's interest and he manages to cite examples of products that emerge at the end of the processing workflow. The sections on image matching and elevation extraction are especially fulfilling. The part on orthorectification includes this apt remark (p. 217): "Qualified orthoimages should be corrected manually for deformed bridges to avoid scepticism of orthoimages."



HIGH RESOLUTION OPTICAL SATELLITE IMAGERY 2ND EDITION

IAN DOWMAN, KARSTEN JACOBSEN, GOTTFRIED KONECNY AND RAINER SANDAU.

- Whittles Publishing, Dunbeath, Caithness, Scotland, 2022.
- 247 x 175 mm, xvi + 271 pp, 202 color and black and white illustrations, 28 tables, index.
- Hardback, ISBN 978-1-84995-390-0, £95.

Chapter 8, "Applications," by Dowman and Jacobsen, on the other hand, is quite short and does little more than scratch the surface of what is possible with modern satellite imagery. This is acceptable, because this topic could so easily swamp the book if any sort of comprehensive account were attempted. Dowman assumes the responsibility of the final chapter, "Conclusions and future

continued on page 47

AI-BASED
MEMS GNSS/INS

CERTUS EVO

- 0.03 ° Roll & Pitch
- 0.05 ° Heading
- 0.2 ° /hr Bias Instability
- 10 mm Position Accuracy

CERTUS EVO

AI-Based Navigation System

Certus Evo is an AI-based MEMS GNSS-aided INS that provides extremely accurate position, velocity, acceleration, and orientation under the most demanding conditions. It offers FOG-like performance combined with the reliability and affordability of MEMS sensors. It features low SWaP-C (Size, Weight, Power, and Cost), internal data logging, and multiple communication interfaces for easy integration.

ADVANCED NAVIGATION