# GIM INTERNATIONAL

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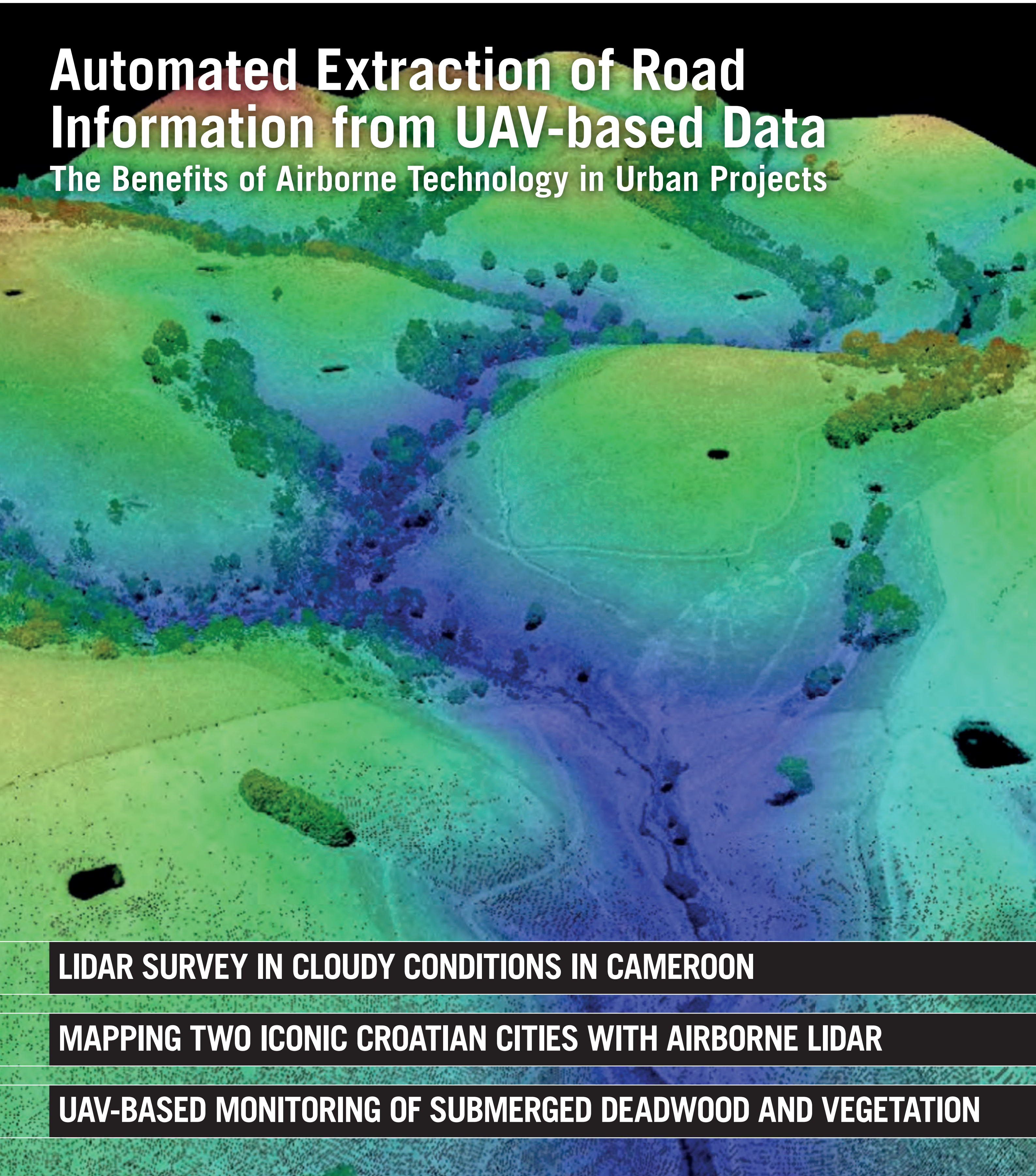


# Automated Extraction of Road Information from UAV-based Data

## The Benefits of Airborne Technology in Urban Projects

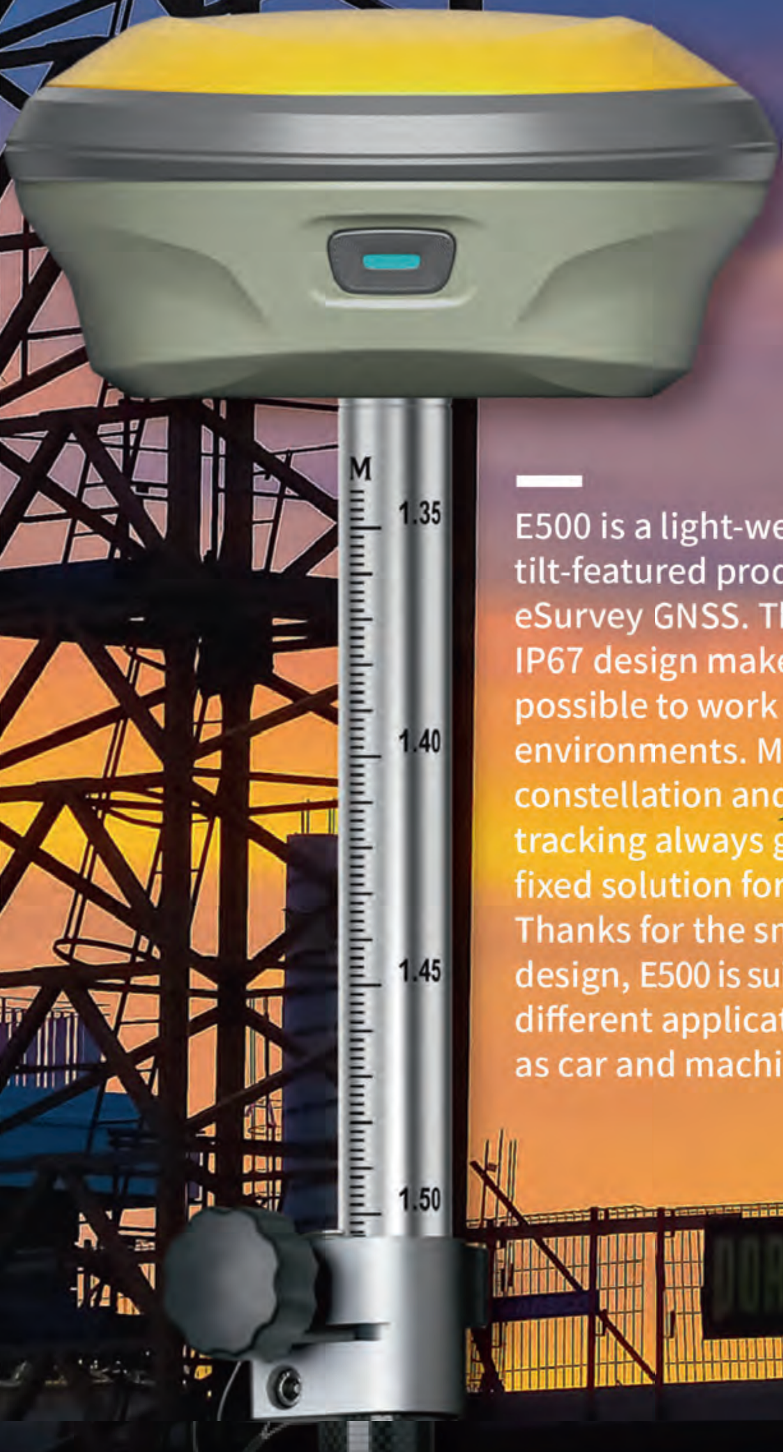
LIDAR SURVEY IN CLOUDY CONDITIONS IN CAMEROON

MAPPING TWO ICONIC CROATIAN CITIES WITH AIRBORNE LIDAR

UAV-BASED MONITORING OF SUBMERGED DEADWOOD AND VEGETATION e-survey

# E500

## Tilt-featured RTK Receiver

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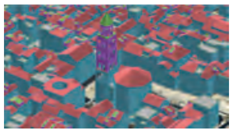



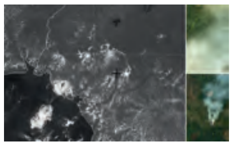



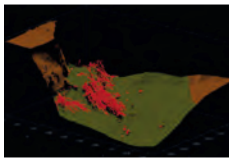



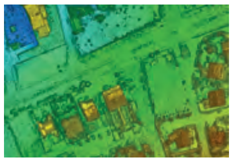






## COVER STORY

The front cover of this edition of *GIM International* shows a point cloud of the Golden Plains Lidar project with elevation symbology. The Digital Twin Victoria (DTV) Program is investing over AU$4 million in new Lidar surveys across the Australian state of Victoria to support a range of land and infrastructure management activities. The data acquired through this project will enable the production of Victoria's first state-wide high-resolution digital elevation model, the Vicmap 1M DEM, which will be a 100x improvement on the existing Vicmap 10M DEM.

# Earth Overshoot Day

“If everybody lived like people in the Netherlands, we would need 3.6 Earths. It would take 7.3 Netherlands to regenerate everything the country’s residents demand from nature,” according to the Earth Overshoot Day website. Earth Overshoot Day is the date when humanity’s demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year. In other words, from that day onwards we are living in debt to our planet.

The Global Footprint Network organization calculates the Earth Overshoot Day not only for the whole world, but also at country level – and there are overwhelming differences between the various nations. The Global Footprint Network’s list of countries reveals that my home country – the Netherlands – reached its overshoot day on 12 April, which is slightly behind Canada, the USA, Australia and South Korea. In contrast, Indonesia, Ecuador and Jamaica will not reach their Earth Overshoot Day until December. In 2021, the global Earth Overshoot Day was on 26 July.

If you’re curious about your own influence on the climate and the environment, you can pause to critically reflect on how sustainable your lifestyle is. How do you live, what do you eat and how do you travel? The answers to these questions provide information about your personal ecological footprint and inspiration for how you could reduce it. But you can also consider this from two angles as a geospatial professional. Firstly, how can you make your business operations more sustainable? And secondly, how can the our industry contribute to a smaller ecological footprint?

Thanks to the arrival and ever-increasing availability of so much relevant technology, reducing greenhouse gas emissions is no longer rocket science. For companies in the land surveying sector, the first step is to improve the sustainability of their own business operations. Dutch land surveying company Geomaat is one example of what can be done; it has completely disconnected its offices from the gas supply and is well on the way to transitioning its entire fleet to electrically powered vehicles. At the same time, there is growing demand for sustainable geospatial business solutions. FIG President Rudolf Staiger recently told *GIM International* that the majority of the global players in the surveying and geospatial industry are high-tech companies with powerful R&D departments. They can play a key role in contributing to a safer and more sustainable world by developing innovative products. He is right, of course. For example, climate change can be tackled by helping people to lead a smarter lifestyle, not only in smart cities but also by developing solutions for rural areas. Spatial information, big data, surveying, BIM, land administration and other areas of geomatics expertise are all essential factors in this context.

The exact point in the calendar year that Earth Overshoot Day occurs depends on how quickly humanity depletes the planet’s resources, including by engaging in deforestation, emitting greenhouse gases by burning fossil fuels and also overfarming/overfishing. We have now reached the decisive years; will we manage to push the ‘Stop’ button on climate change in time? When I was a youngster, the Dutch government ran a public information campaign based around the following slogan: “A better environment starts with you”. With this in mind, I think we can all do something to make our own personal – and professional – lives greener.

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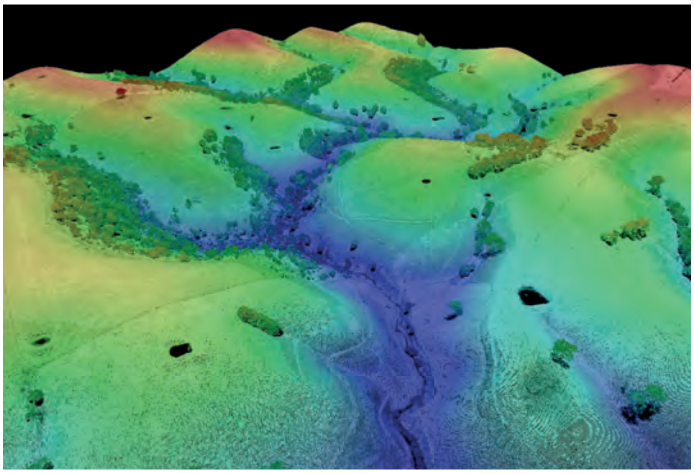
# Australian State to Conduct Ambitious Lidar Survey Project



▲ *Point cloud of the Golden Plains Lidar project (Victoria, Australia) with elevation symbology.*

The Digital Twin Victoria (DTV) programme is investing over AU$4 million in new Lidar surveys across the Australian state of Victoria to support a range of land and infrastructure management activities. These activities include site investigations, flood mapping, vegetation mapping, surface modelling, cultural heritage mapping and land surface change detection. The DTV programme is a four-year historic initiative running to 2024 that will harness digital innovation, emerging technologies and geospatial data to unlock economy-wide savings through Victoria's Big Build and leverage the digital acceleration underway in response to COVID-19. Commencing in 2022 and due for completion in 2023, this project under the DTV programme will be the largest-ever Lidar survey conducted by Victoria's government. The survey will provide the high-quality elevation data needed by digital twins for accurate 3D visualization and analysis.

# Leica Geosystems Launches Tilt-compensated Total Station Pole Solution

Leica Geosystems, part of Hexagon, has introduced the Leica AP20 AutoPole, an innovative solution for automated total stations that boosts productivity to the next level through tilt compensation, automatic pole height readings and unique target identification. The AP20 AutoPole combines an intelligent sensor module with the new AP Reflector Pole and operates with Leica Geosystems' existing automated total stations to create an advanced solution for autonomous workflows. It opens up new possibilities and solves three common workflow challenges: holding the pole vertical and stable, entering the pole height manually into the field software, and locking to a foreign target on a site with multiple reflectors. The innovation is another step towards autonomous workflows in line with Hexagon's mission to develop autonomous solutions that lead to increased productivity, safety and sustainability.

▲ *The tilt compensation of the AP20 AutoPole increases efficiency when working with total stations.*

# Datumate Wins Tender to Monitor German Railway Infrastructure Projects

Deutsche Bahn AG has awarded a multi-year tender to Datumate for the analysis and visualization of drone images related to its railway infrastructure. Datumate is a leading provider of construction data analytics for the infrastructure construction industry. As part of this framework service agreement, Datumate will provide services based on DatuBIM, its cloud-based construction data analytics platform, for digital progress monitoring of construction projects, quality assurance and comparison of schedule versus plan. DatuBIM automatically generates as-built 3D models, gives construction data alerts, delivers analytics to assess site conditions and construction progress, fosters team collaboration, preserves evidence and documents the project. Infrastructure construction projects often span several years. This tender enables Deutsche Bahn AG construction projects to use Datumate's services for a two-year term, with an optional additional two years. The tender award further expresses the importance of digital construction management. Entering the era of connected construction sites with digital collaboration, progress monitoring and analytics will dramatically increase the probability of finishing projects on time and budget and will improve the supervision of general contractors working for Deutsche Bahn, according to Tal Meirzon, Datumate's CEO.


▲ *An InterCity Express (ICE) high-speed train in Munich, Germany.*

# 3D Models Support Solar Farm Planning in Ireland

3D maps derived from the latest aerial photography are being used to secure planning permission for solar farms across the Republic of Ireland. Created by Bluesky International, the digital terrain and surface models (DTM/DSM) are applied by an Irish landscape consultancy firm to better understand how solar farms could be seen from the surrounding area and the impact reflected light might have on existing properties and infrastructure. Working on behalf of solar energy developers across the republic, landscape consultancy firm Macro Works uses Bluesky's models to produce several outputs, including Zone of Theoretical Visibility (ZTV) maps and Glint and Glare assessment reports. These, together with a Landscape Mitigation Plan, have already helped secure permission for over 100 solar farms, including Ireland's largest permitted development to the north-west of Midleton, County Cork.


▲ ***DSM data allows screening by existing vegetation and buildings to be accounted for and also allows proposed mitigation to be incorporated and so that its effectiveness can be examined.***

# Dutch Mapping Company Creates Digital Twin of Historical Gateway

4Indoor has used a wearable NavVis VLX mobile mapping system to create a high-quality 1.2GB point cloud of the mediaeval gateway called Koppelpoort in the Dutch city of Amersfoort. 4Indoor, a 3D measuring specialist based in Amersfoort, wanted to digitally capture historical unique and beautiful places in the city. The company conducted this ambitious reality-capture project in the historical centre of Amersfoort using a NavVis VLX mobile mapping system. Together with over 850 panoramic HD images, it was possible to completely digitize the premises, creating an accurate digital twin of all the historical buildings that make up the gateway. This includes as-built floor plans and sections created with the help of the high-quality point cloud comprising billions of points. NavVis IVION gives the building owners remote access to the digital assets – completely independent of their location – using any standard web browser on a laptop, tablet or smartphone.

▲ ***Point cloud of the mediaeval Koppelpoort gateway in Amersfoort.***

# PlanetObserver Launches New 10m Global Imagery Basemap

PlanetObserver has released PlanetSAT Global 2022, a basemap that provides ready-to-perform, cloudless and homogeneous imagery. With outstanding 10m resolution, PlanetSAT Global imagery basemap provides access to detailed geographic information from global scales all the way down to 1:50,000 map scale. One major feature of the PlanetSAT basemap is the updates that PlatetObserver releases on an annual basis. The company states that outdated imagery is often of little or no use for many projects and solutions. Annual updates ensure that users can access the most current image layer available. For PlanetSAT Global 2022, more than 10 million square kilometres of fresh 10m imagery have been ingested in the global basemap. The main updated areas include the USA and the United Arab Emirates. In addition, over 170 major cities worldwide have been updated.

▲ ***PlanetSAT Global 2022 imagery of Hainan, China. (Image courtesy: PlanetObserver)***

# European Space Imaging Renews Contract with Maxar Technologies

European Space Imaging and Space Imaging Middle East have extended their long-standing partnership with Maxar Technologies to continue acquiring and supplying very high-resolution satellite imagery to Europe, North Africa and the Middle East. Maxar Technologies is a provider of comprehensive space solutions and secure, precise geospatial intelligence. European Space Imaging has been acquiring satellite imagery from Maxar satellites since 2003 through its multi-mission ground station at the German Aerospace Centre. This renewed agreement will see the company expand on previous investments to upgrade the ground station. New upgrades will include the tasking of the upcoming Legion satellites with near-real-time provision, as well as improving delivery times of currently orbiting satellites. In addition to collecting imagery over Europe and leveraging the extensive Maxar archive for customers, European Space Imaging will continue to offer innovative Maxar products such as 15cm HD, SecureWatch, Analysis Ready Data (ARD) and a range of 3D products and tools.

▲ ***WorldView Legion is a fleet of high-performance satellites that expands the ability to revisit the most rapidly changing areas on Earth to better inform critical, time-sensitive decisions. (Image courtesy: Maxar)***

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# A60 Pro

## IMU-RTK GNSS Receiver

- Multi-channel technology (GPS,Glonass,Galileo,Beidou)
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# Smartphone Solution with Survey-grade Mapping Accuracy

MetaSpatial Solutions' new platform-agnostic SmartSurveyor system turns any smartphone (iOS/Android), tablet or low-cost consumer-grade drone into a precise mapping system with 2cm mapping accuracy in XYZ. MetaSpatial Solutions is an Australian-based geospatial and mapping technology company. The SmartSurveyor product concept is born as a result of 23 years of active geospatial and mapping product development. It uses a mixture of sciences and technologies for collecting and producing precise mapping data, and is aimed at doing this at a fraction of the cost and time compared with any other solutions. "We have packaged all the surveying, photogrammetry, mathematics, physics, sensor calibration, datum transformation and error adjustment complexities in a single software and hardware package so it can be simply operated by anyone," said Adam Chabok, director at MetaSpatial Solutions and inventor of the solution.

▲ *MetaSpatial's platform-agnostic SmartSurveyor system.*

# Australian Firms Team up to Deliver High-resolution Hyperspectral EO Microsatellites

LatConnect 60 and Gilmour Space Technologies will work together to build and launch the first microsatellite in a planned high-resolution hyperspectral imaging constellation. The smart satellites will be placed in 30-degree inclined orbits for frequent revisit data capture over the Earth's equatorial and mid-latitude regions.

▲ *Canberra Capital Hill satellite imagery. (Image courtesy: LatConnect 60)*

LatConnect 60 (LC60) is an Earth observation and data fusion company based in Perth, Australia."HyperSight 60 will deliver geospatial insights for mid-latitude areas at a level of detail and frequency not possible with other commercial remote sensing systems," said Venkat Pillay, LC60 CEO and founder. "The addition of Gilmour Space to the LC60 team contributes significantly to the future success of our ambitious plans." The first HyperSight 60 microsatellite is planned for launch in Q4 2024. Once the entire eight-satellite constellation is operational, an hourly revisit rate will be possible at mid-latitude locations between 30 degrees north and south in Australia, Asia, South America and Africa. This revisit, combined with the spectral bands collected in high- and medium-spatial resolution, will deliver timely information-rich insights for agriculture, forestry, environmental, mineral/ oil & gas, climate change, maritime and defence applications.

# Lidar Point Cloud Models Visualized in 3D-Stereo

For consistent and precise digital GIS and photogrammetry workflows, raw data must first be converted into integrable and thus valuable information components that meet the requirements of the respective application environments. The 3D point cloud processing modules from the Finnish software provider Terrasolid are highly developed, intelligent and powerful applications. For the spatial viewing and measurement of 3D models, TerraStereo relies on the detailed high-contrast 3D-stereo display of passive, double-screen beamsplitter systems, the 3D PluraView series from Schneider Digital. Terrasolid's solutions are able to process and model laser points with their XYZ coordinates at high speed and can also display the result in 3D-stereo. During the last 20 years, the capabilities of the available Lidar hardware has developed rapidly together with the capabilities of the processing software, with Terrasolid applications at the forefront.

▲ *Terrasolid users benefit from mature 3D visualization technology with the 3D PluraView monitors.*

# Visualizing a Prolific Future

As we seek to effectively respond and adapt to the challenges of our changing world, it is insightful to look back over time at how humanity has used location information to overcome dire circumstances. After all, people throughout history have used geographic insights to solve problems when faced with socio-economic constraints like famine, environmental challenges such as severe weather, and security threats with constant wars. As we continue to face these and other issues today, it is also important to look at how taking a geographic approach increases our ability to visualize and analyse challenges, and to transform how we plan, make decisions and take actions toward a sustainable future.

In my recent *GIM International* article titled 'Innovation Drives the Continuous Evolution of Data Visualization', I made the case that data visualization is inherently beneficial to humans and continuously evolves with innovation. Visualizing and analysing geographic data has benefited us socio-economically, environmentally and for our security throughout history. As people leverage innovation and GIS, data visualization and analysis has rapidly evolved with the number of applications and uses. These enable better decision-making to address the challenges we face today (Figure 1) and turn them into our opportunities for tomorrow (Figure 2).

## GIS DATA VISUALIZATION AND ANALYSIS ENHANCE OUR UNDERSTANDING

As covered in my previous article, data visualization and analysis has been used in various ways throughout time and, more recently, expanded in the applications and uses made available by geographic information systems (GIS). GIS enable us to visualize our data and analyse it, turning it into actionable information using a geographic approach. This provides location-based insights and understanding, which proceeds action and supports better decisions.

Visualization of geography changed dramatically when we started putting sensors on airborne platforms. Valuable information could then be identified and extracted by image analysts and geospatial analysts. In the past, this has proven to be labour-intensive and time-consuming as these analysts look for features in the imagery (figuratively "looking for a needle in a haystack"). GeoAI – the combination of GIS with artificial intelligence (AI), machine learning (ML) and deep learning (DL) – is rapidly revolutionizing this process. By training and running GeoAI models to identify and extract elements such as buildings and transportation features and by doing change detection for land use and agricultural transitions, we are accelerating our ability to collect, manage and produce information.

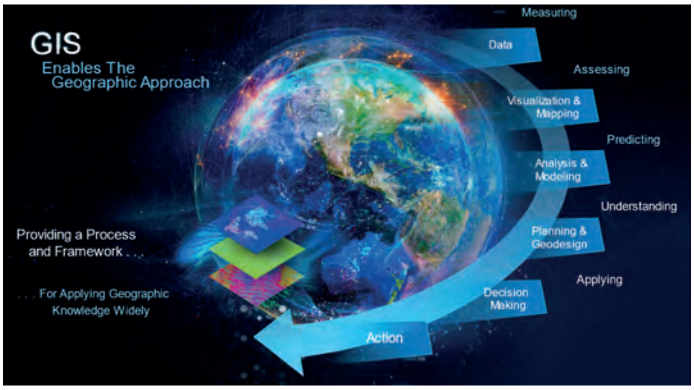
Sensors on airborne platforms have expanded beyond imagery in the visible optical window to infrared and spectral imaging across the electromagnetic spectrum. The integration of image processing and GIS has allowed us to exploit the strengths of both, bringing context to imagery and timeliness to GIS data. It has advanced our capabilities of discovering new insights from sensor networks, hyperspectral imaging and spatiotemporal data cubes and image cubes. These have provided the ability to look at and geospatially analyse changes in Earth's terrestrial, atmospheric and marine environments. This change detection enables us to understand, mitigate and remediate issues from climate change such as shoreline erosion, desertification and deteriorating biodiversity issues. The geographic approach provides us better understanding by leveraging geoprocessing and spatial analysis for disaster and risk management, socio-economic impacts, food and water security and many other applications that are critical to sustaining life on Earth.

▲ *Figure 1: The challenges of our changing world.*

Other types of sensors on airborne, spaceborne, marine and terrestrial platforms provide additional remote sensing capabilities, like light detection and ranging (Lidar), synthetic aperture radar (SAR), particularly interferometric synthetic aperture radar (InSAR), pollution sensors, water/tide gauges and more. The sensor data can be easily visualized and analysed in relationship to other physical and cultural geographic phenomena using GIS to enhance our understanding. Spatiotemporal analysis of the sensor data opens windows of time and understanding of our historical environs through to the present and allow us to model and help predict our future.

## 3D REALITY CHECK

Many types of sensor data have been used to support 3D visualization, modelling and




▲ *Figure 2: The geographic approach empowers understanding, evidence-based decision-making and informed actions.*


▲ *Figure 3: Innovation spawned by GIS capabilities and a geographic approach help us to address the world's challenges.*

analysis. The significant cost of producing high-resolution 3D data of the natural and human built environments has traditionally limited us to small areas of interest and high-value urban areas. Historically, 3D analysis was constrained by computing and storage resources. However, thanks to advances in computation, 3D GIS now works across desktop, enterprise, web, mobile and even cloud environments using web services for visualization and analysis.

Integrating topographic and bathymetric data for entire countries has always been challenging, but remotely sensed data and GIS is beginning to make this a reality. Large 3D GIS datasets from government planning, land administration and national mapping geospatial authorities are integrated with highly detailed building information modelling (BIM) and computer-aided design/drawing (CAD) data from the architecture, engineering and construction (AEC) industry, coming together with GeoBIM. Reality capture provides 3D meshes with intelligent GIS-attributed data. Planning with GIS is facilitated by ArcGIS GeoPlanner for green infrastructure and ArcGIS Urban for built environments. The reality is that 3D is increasingly easier to visualize and analyse in GIS, making it possible to create higher resolution and better quality digital twins of our world.

## KEEPING THINGS SIMPLE AND SWEET

While data visualization and analysis is very valuable, it can be quite complex and confusing for decision-makers and other people who could otherwise greatly benefit from the information to make evidence-based decisions. Fortunately, simple-to-use browser-based GIS apps can do that rather quickly. GIS dashboards can aggregate dynamic data from sensor feeds, authoritative information providers, crowd-sourcing and other sources in near real time in easy-to-understand apps, similar to dashboards in a car. As data is turned into actionable information, it can be communicated through storytelling tools such as StoryMaps to help people intuitively understand and confidently make trusted decisions. If those actions need to be made by consensus for community planning or to address common issues, all the above data can be revealed in the context of GIS Hubs and initiatives to support collaboration and ultimately provide answers to stakeholders' and citizens' questions around those initiatives. If further analysis or predictive analytics is required, the data can be made available in a portal for ease of access and use.

## GIS LEVERAGES TECHNOLOGICAL INNOVATION

GIS running in desktop, enterprise, web, mobile and cloud environments, using a geographic approach, is a force multiplier to not only visualize data, but also analyse and effectively utilize it in apps and use cases to support better problem-solving. Utilizing AI, ML, DL, imagery and GIS, GeoAI is automating and transforming change detection and extraction of data in our rapidly changing world. The ability to process, mine and use big data and real-time velocity data efficiently in the cloud using GIS analysis brings new insights and understanding to today's fast-paced global economy and constantly modified environment.

## WHAT DOES THE FUTURE HOLD?

With humankind's inherent need to visualize and understand data and our ability to constantly innovate, our future can be bright if we apply GIS to mitigate the significant issues of our times and make the best decisions possible going forward. Data visualization and analysis through GIS enables us to measure, understand and act through informed evidence-based decision-making on the critical challenges impacting our world. As humanity continues to innovate and reap the socio-economic, environmental and security benefits from data visualization and GIS analysis, the opportunities for GIS capabilities to proliferate may be as broad and diverse as the electromagnetic spectrum (Figure 3). ◀

### *FURTHER READING*

https://www.esri.com/en-us/about/climate-change/overview
https://www.esri.com/maps
Innovation Drives the Continuous Evolution of Data Visualization, *GIM International*, Vol. 35, issue 7 2021

### *ABOUT THE AUTHOR*

**Mark Cygan** is director of national mapping solutions at Esri. He has been working in GIS and mapping since 1984, and has been in Esri's Industry Solutions Group since 2005. Before that, he worked for nearly a decade as a senior consultant and project manager in Esri's Professional Services. Prior to joining Esri, Cygan was on the management team at NAVTEQ (now HERE), a pioneer in digital mapping for in-vehicle, web and mobile uses. Cygan is actively participating in the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) is a UN-GGIM Geospatial Societies board member (and past chair), is the executive secretary of the User Community for Geospatial Authorities and is on the board of directors of the International Map Industry Association (IMIA).
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MODERN AIRBORNE REMOTE SENSING FOR COMPLEX CITY MODELLING

# Mapping Dubrovnik and Split with Integrated Airborne Sensor Systems

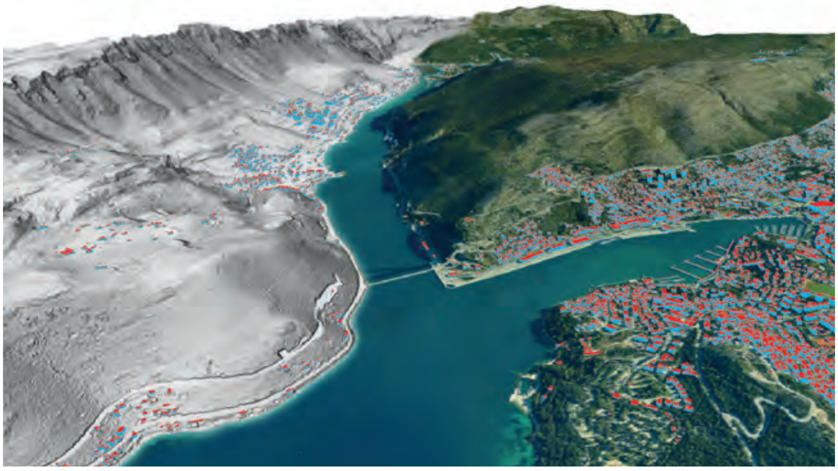
Nowadays, both image-based solutions and laser-scanning methods are evolving rapidly, but there is much debate about which technology is more efficient. Integrated airborne sensors, in which imagery and Lidar data are complementary, can provide interesting new opportunities, especially in complex situations such as city mapping.

City planners require ever-more accurate, detailed and up-to-date geographical information. Whereas the high-resolution digital orthophoto was a big step forward to capture such detailed information 20 years ago, much more is needed today; a digital orthophoto alone is not sufficient. Eurosense recently had the opportunity to model two iconic Croatian cities: Dubrovnik and Split.

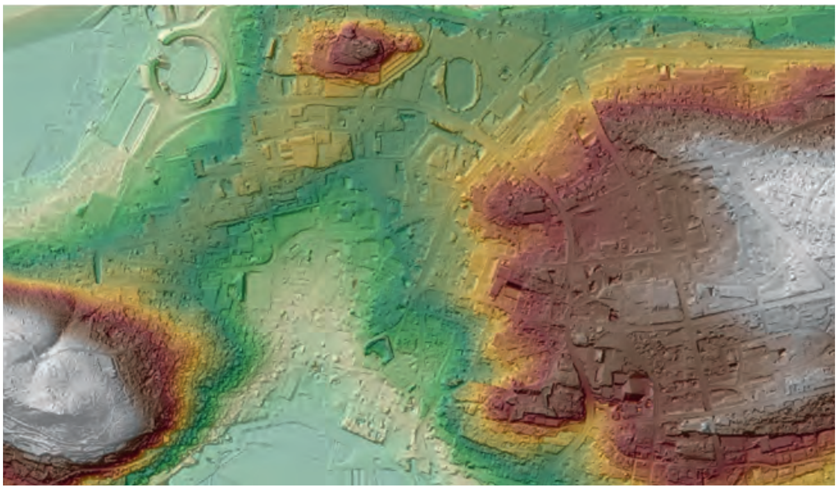
In view of the project complexity, integrated airborne sensing combining imagery and Lidar data presented an effective solution.

## CHALLENGING GEOGRAPHICAL CONDITIONS

Both have very difficult relief and landscape. Local elevation differences in the areas of interest exceed 1,000m, including extremely steep and rocky shorelines. Landscapes are equally complex with very dense historical city centres, narrow streets and relatively high buildings. For example, in some dense and steep built-up areas, the elevation of the ground just 2-3m behind the building is often higher than the absolute elevation of the highest roof point of the building.



▲ *Figure 1: Lidar DTM of a part of Dubrovnik with orthophoto and buildings.*



▲ *Figure 2: Lidar DTM of a part of Split.*

These projects were also made more complex by the large number of different products required by the clients. For example, for both cities it was necessary to produce high-resolution RGB stereo imagery, high-density Lidar data, a classified Lidar point cloud, an RGB orthophoto mosaic, Lidar DTM and DSM, and an LOD 2.2 building model. For Split, it was additionally necessary to produce a high-resolution true orthophoto, an LOD 2.2 building model in CityGML format and a 3D mesh model of the city centre.

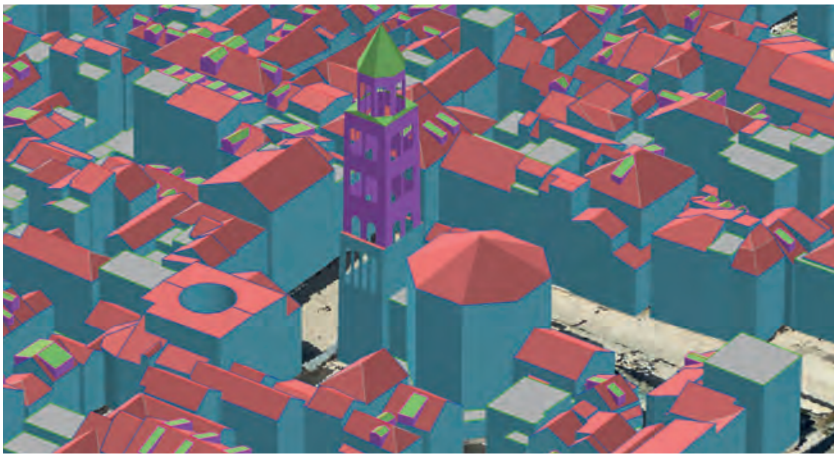
## DATA ACQUISITION AND SENSORS

Proper selection of sensing equipment is crucial to the successful acquisition of scan data and imagery of such demanding areas. The detailed digital representation of dense urban space requires high-resolution and accurate scan data, with the particular necessity of being able to scan narrow street canyons with a minimum of shadowing and the capability of scanning vertical facades. The decision was made in favour of the RIEGL VQ-1560II and the VQ-1560i-DW – laser scanning systems of the latest generation featuring full waveform digitization and online waveform processing. Both systems operate a dual laser channel design, enabling forward/nadir/backward-looking capabilities with highly homogeneous point density distribution, which has proven advantageous in urban scanning. The two laser channels of the VQ-1560II operate at the infrared wavelength of 1,064nm, whereas the VQ-1560i-DW is a dual-wavelength instrument, with one channel operating at 1,064nm and the second channel operating at 532nm, i.e. green laser light. A mandatory high-grade inertial navigation system, a flight management system and up to two digital cameras complete the systems.

For the Dubrovnik area, the VQ-1560i-DW sensor was used with an integrated mid-format 100MP RGB PhaseOne camera. Images were captured at AGL=1,033 with a ground sample distance (GSD) of 10cm, and the average point density of the laser scan data was 24.5 points/m$^2$.

For the area of Split, Eurosense used its own aircraft and own VQ-1560II sensor with integrated mid-format 150MP RGB PhaseOne camera, flown at an altitude of 1,330m AGL, with an image GSD of 10cm. Due to the 80% side overlap, the average point density over the city was more than 90 points/m$^2$. This high point density produced a robust Lidar database as the basis to build a precise digital terrain model (DTM) and digital surface model (DSM) and to execute reliable classification into 12 classes for both cities. The DTM and DSM were produced with 0.5m resolution in ESRI grid.

▲ *Figure 3: A fragment of the LOD 2.2 building model of Split.*



▲ *Figure 4: LOD 2.2 model of the iconic historical tower of Split with its complicated structure.*

## SPECIAL TECHNICAL SOLUTIONS

Several special technical solutions were used to overcome the challenges that arose from the complexity of the landscape and the difficulty level of the projects: high-precision aerial triangulation, LOD 2.2 buildings, a true orthophoto and a 3D mesh model.

### *High-precision Aerial Triangulation*

*One of the technical challenges was to achieve a high-precision vector building model by stereophotogrammetric extraction using mid-format camera images. Therefore, special attention was given to the accuracy of aerial triangulation during data processing. To get the required accuracy, recurrent self-calibration of the camera was performed and Lidar data was used in addition. Furthermore, the option of DTM was also applied in MATCH-AT which significantly increased the accuracy of the triangulation of PhaseOne images. The triangulation block over the dense city area of Split consisted of 697 PhaseOne images. In terms of the achieved accuracy, the root mean square error (RMSE) on 19 full (X,Y,Z) ground control points (GCPs) was RMSEX=RMSEY=±5.5cm, RMSEZ=±12.2cm. 39 check points were used to validate the achieved accuracy, giving the following result: RMSEX=±8.7cm, RMSEY=±8.0cm, RMSEZ=±10.9cm. This accuracy is fully appropriate for precise 3D building vector extraction. To provide the most efficient use of PhaseOne images with their full triangulation result in different stereophotogrammetric applications, synthetic 'undistorted' images were also produced.*

### *LOD 2.2 Buildings*

*The densely built old city of Split with complex building roof structures presented a special challenge. More than 30,000 buildings were extracted. Besides the geometrical precision, another important aim was to create correct multilevel topology and an object-oriented building database, whereby each building was a separate multi-polygon entity. All buildings fit perfectly with the DTM.*

### *Orthophoto/True Orthophoto*

*In the technical specification of the project, a 10cm traditional orthophoto mosaic was requested. Due to the challenging city structure, it was not possible to achieve acceptable quality of the traditional orthophoto mosaic, even with high image overlaps. Therefore, the project team decided to produce a true orthophoto. However, the result of the first trial did not achieve acceptable quality. The quality of the initial DSM was improved on the second attempt by using vector building data and dense Lidar data. With the improved DSM, the quality of the resulting true orthophoto mosaic was significantly better and fitted perfectly with the extracted building vectors.*

### *3D Mesh Model of the Centre of Split*

*As the improved DSM resulted in a true orthophoto with much better quality, it was decided to produce a 3D mesh model of the city centre by using aerial triangulation results improved with additional involvement of Lidar data. Additionally, the complementary use of Lidar and vector data significantly improved the quality of the 3D mesh.*

## UNIQUENESS OF THE DUBROVNIK PROJECT

A unique feature of the Dubrovnik project was the use of the green channel of the RIEGL VQ-1560i-DW. While this instrument was primarily designed for collecting scan

▲ *Figure 5: A fragment of the traditional orthophoto of Split.*

▲ *Figure 6: The same fragment of the true orthophoto with extracted building vectors.*

data of vegetation, this scanner has a unique capability to penetrate water and reach the seabed. This depends on the turbidity of the water, of course, but the crystal-clear water along the shores of Dubrovnik produced very promising results. Clear waters are quite common elsewhere in the Mediterranean and Adriatic regions, for example, so this technology could hold potential for larger-scale mapping of the seabed close to the shoreline. As an indication of the penetration depth of the green Lidar beam, this project flew at 1,033m above ground level and obtained returns from the seabed at more than 10m depth in some locations. However, this depth was not reached everywhere; generally speaking, penetration was much stronger near to the nadir and significantly less off nadir.

## CONCLUSIONS

The first and general conclusion is that the use of both types of data – imagery and Lidar – allows increased accuracy and spatial resolution of the final products as well as faster and more cost-effective data services. Additionally, special technical solutions make it possible to obtain high geometrical accuracy from mid-format cameras. However, the questions remain whether the increased price of such additional efforts compared to the costs of using large-format photogrammetric frame cameras would justify the required quality level. Another conclusion is that the necessary high accuracy of aerial triangulation of PhaseOne images for vector mapping can be reached just using additional efforts like recurrent self-calibration and complementary use of Lidar data. In order to obtain a high-quality true orthophoto, special attention must be given to the improvement of the initial, automatically filtered DSM received from dense point matching. Moreover, the quality of the DSM is an important factor in the final quality of the true orthophoto and the quality of the 3D mesh model. Therefore, it is essential to have the correct and sufficient tools to improve the quality of the DSM by adding complementary constraints and to have an opportunity to edit the initial DSM. Lastly, the authors conclude that they have shown that, under certain conditions, with the correct flight planning and setup of the

▲ *Figure 7: A composition of 3D mesh model and Lidar point cloud of Split city centre.*

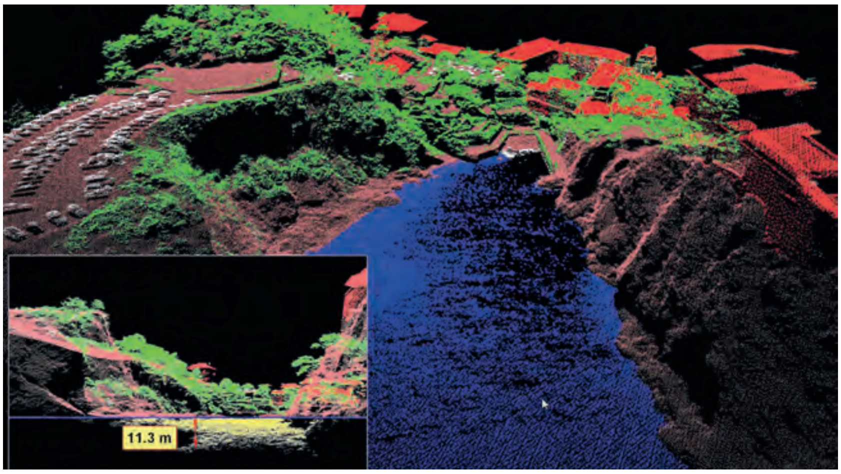



*Figure 8: Dubrovnik, showing penetration of the green channel of RIEGL VQ-1560i-DW into the water.*

green channel of the RIEGL VQ-1560i-DW, this technology can be used successfully for underwater mapping down to depths of 10-12m in the Mediterranean and Adriatic Sea region. The precise conditions and constraints will require further investigation.

**ACKNOWLEDGEMENTS**

Eurosense executed the two Croatian projects presented in this article for GDi LLC. The primary users of the data are the cities of Dubrovnik and Split. OPEGIEKA (Poland) – as subcontractor of Eurosense – performed the flight over the city of Dubrovnik using its unique dual-wavelength laser scanning system, RIEGL VQ-1560i-DW.

## ABOUT THE AUTHORS

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# Dam Fine Data: Sub-millimetre-resolution UAS Dam Surveys

In early 2021, the Orthodrone team crowded itself and its equipment into a tiny Swiss gondola and made its way to one of two dams scheduled for water-side inspection – no easy feat, given the metres of snow closing off many alpine roads during the winter. Often situated in difficult-to-reach locations, Swiss pumped storage plants can greatly benefit from sub-millimetre-resolution uncrewed aerial system (UAS) dam surveys. With the appropriate survey-grade, metric sensors, current UAS can offer safer access and increased cost-effectiveness compared with more traditional inspection methods, while providing comparable or better data.

▲ *Low water levels cause turbine downtime, which can be significantly reduced using uncrewed surveys.*

**MUCH MORE THAN CHOCOLATE, KNIVES AND CLOCKS: SWISS HYDROPOWER**

Well over half of the energy produced in Switzerland comes from hydropower, and Axpo Holding AG is Switzerland's largest hydropower producer. The canton of Graubünden, where this project took place, contributes over 20% of the electricity generated from hydropower in the country, totalling more than 7.9 billion kilowatt hours per year.

Most of the hydropower in Switzerland comes from storage power plants and run-of-river plants, with only 4.3% of Swiss hydropower provided by pumped storage hydropower plants. However, pumped storage plants are an important component of a hydropower system, helping to balance supply and demand. In a pumped storage system, reservoir water is sent through pressure pipes to drive turbines that generate electricity to be fed into the power grid. In addition to providing energy during peak usage, pumped storage plants also allow for the conversion of excess electricity from the grid through the transfer of water from the lower reservoir to the higher reservoir during off-peak periods. This makes them a vital resource for smoothing energy consumption.

Traditionally, water-side inspections of the dams have caused significant turbine downtime.

**SWISS DAM SAFETY: AN INTERNATIONALLY RECOGNIZED REGULATORY SYSTEM**

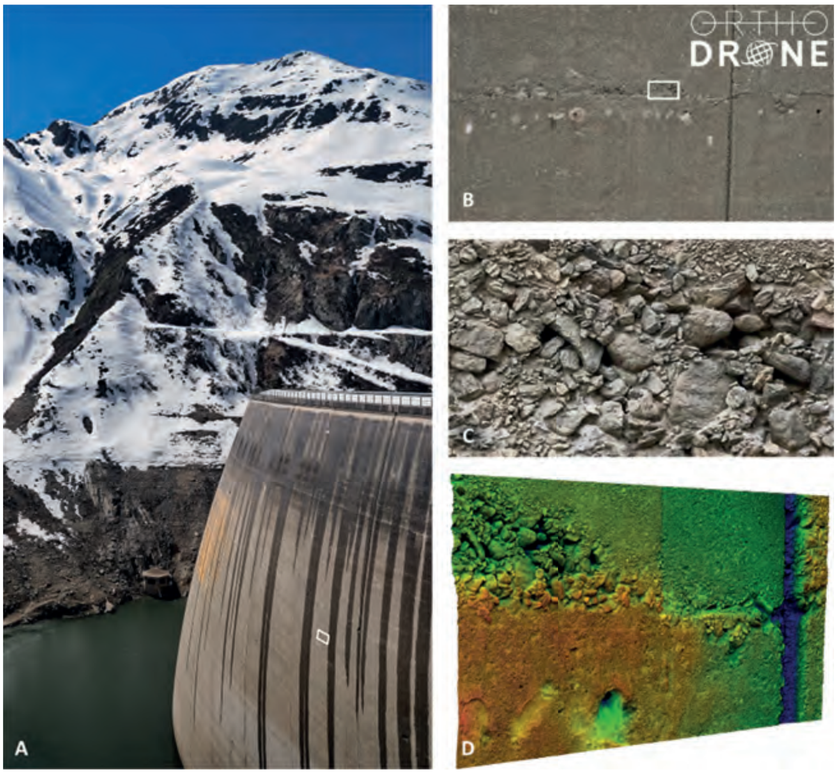
Throughout the lifetime of a dam, appropriate operation and consistent maintenance are essential for minimizing risk. Regular inspection helps to ensure the safety and continued operation of a dam, an area in which Switzerland – highly praised by the International Commission on Large Dams – has excelled, having had no dam failures since 1887. However, conventional dam inspections require resource-intensive data collection by means of workers atop platforms suspended from the dam, providing a prime use case for UAS dam surveys to improve inspection safety and efficiency.

Unlike popular consumer-grade drones, Orthodrone's equipment includes made-to-measure UAS and metric cameras, made specifically for surveying and inspection. Phase One's iXM100 is its favourite tool for photogrammetric data acquisition, allowing the Orthodrone team to get the sub-millimetre-resolution data required for a detailed analysis of the safety of a dam. Compared to cameras such as the DJI Zenmuse P1, the iXM100 not only has superior image quality, but also a faster trigger: within the typical two-second trigger interval for a single shot of the DJI P1, the iXM captures six images – requiring less flight time to capture the necessary data.

With the current setup, the team can achieve a 1.5mm ground sampling distance (GSD), with a footprint larger than 17 x 13m, hovering at about 32m or 60m from the dam face (depending on the lens). A 1mm GSD (footprint roughly 12 x 9m) is possible at a distance of up to ~40m, whereas a 0.5mm GSD (footprint roughly 6 x 4.5m) can be attained up to ~20m from the dam wall.

**COMPLETE CONTROL FOR SHARPER IMAGES**

While utilizing a cutting-edge industrial camera considerably enhances productivity, added automation eases the job. All of our UAS are equipped with real-time kinematic GNSS, Lidar-based rangefinders and complete camera setting control, simplifying not only post-processing, but also allowing for sharper images with spot-on focus. This is particularly important due to the convex shape of most dams, which poses challenges for pilots and their spotters, especially during water-side dam surveys in gusty winds. Of the two dams we surveyed, one was 127m high with a crest length of 480m, and the other was 117m high with a crest length of 560m. Such areas also require terabytes of data storage for the desired sub-millimetre resolution of the images, making them a prime use case for our onboard processing units with significantly larger data storage.




▲ *A: Survey site | B: Single image (cropped height) | C: Image at 100% zoom | D: Point cloud & analysis | GSD: 0.5mm/pix*

**DELIVERABLES – IT'S ALL ABOUT PERSPECTIVE**

With the gathered images and derived multidimensional deliverables, dam managers can assess the dam face for abnormalities or degradation. High-quality data is essential for a thorough assessment of structural integrity, and even the most miniscule cracks can be detected by sub-millimetre-resolution UAS dam surveying. This enables inspectors to identify areas of concern, which are then properly addressed to mitigate risks before they can turn into more costly and potentially more dangerous issues.

Orthodrone is currently working on the development of a new, fully offshore capable, gas-hybrid multi-rotor UAS, which can combine two iXM100 cameras and a survey-grade Riegl Lidar while keeping the entire payload completely stable. Stability is paramount for flying in offshore conditions (or in this case, windy alpine valleys). High wind tolerance will make aborted missions due to high winds a thing of the past. The new system will also be able to carry a single, large focal length lens, enabling inspections at half-millimetre resolution from a distance of 40 metres, allowing for a new level of risk management while gathering the best possible data from afar. ◀

### *ABOUT ORTHODRONE*

Orthodrone is your reliable partner for drone-based critical infrastructure inspections – including sub-millimetre photogrammetric dam surveys in hard-to-reach areas. With hours of hover time and top-of-the-line sensors, Orthodrone is revolutionizing the way we gather, process and utilize spatial data. For a closer look at one of these dams, follow the link below to see the point cloud.

**www.orthodrone.com/data**

### *DYNAMIC FIELD OF VIEW HELPS TO MAINTAIN REGULAR SWATH*

# Lidar Survey in Cloudy Conditions in Cameroon

In Lidar surveys, minimizing flight time is the key to minimizing costs. Operators therefore carefully optimize parameters such as flight altitude, field of view and pulse repetition frequency to cover the survey area at the desired point density with the fewest flight lines. One parameter that they cannot plan for, however, is the weather. This article outlines how a dynamic field of view feature was used in a project in Cameroon to overcome the inability of Lidar laser beams to penetrate the persistent cloud cover.


▲ *Figure 1: The survey area comprised 7,000km² in and around Cameroon's largest city, Douala.*

French survey company Société Topographie Informatique (STI) was contracted by the Communauté Urbaine de Douala (C.U.D.), a regional government body in Cameroon, to conduct Lidar and camera surveys for urban planning and floodplain management. Partially funded by Agence Française de Développement (AFD), the survey would cover a relatively wide expanse of 7,000km$^2$, including Cameroon's largest city and economic capital, Douala, plus areas with natural land cover and large dense forests.

## PREPARING FOR THE SURVEY

In the acquisition phase, close to 200 hours of survey flight time was planned over a period of two months in 2021. The STI team installed a Teledyne Optech Galaxy PRIME Lidar sensor and Phase One IXU-RS 1000 camera in a pressurized bi-turboprop Piper Cheyenne II XL aircraft and optimized the flight plans. While waiting for the right conditions to get the project underway, the team soon found out that the weather would be their greatest challenge. "The biggest problem we faced came in the form of low cloud cover that seemed to encompass the whole area," said Bogdan Munceanu, STI project leader. Cameroon, located in the Gulf of Guinea in west-central Africa, is often described as 'Africa in miniature' because it has all the major climates and vegetation of the vast continent. Unfortunately for the team, Douala suffers heavy cloud cover for about nine months of the year. This is exacerbated by the humidity from the sea as well as haze, dust and perennial bush fires, resulting in constant low cloud cover over the city and its surrounding areas. This poses a problem because one of the limitations of Lidar is that the lasers cannot penetrate dense cloud cover and reach their target. Instead, the clouds 'scramble' the beam which prevents the target of interest (in this case the ground) from being mapped reliably.

## WEATHERING THE CHALLENGES

Realizing the clouds were not going away, Munceanu was quick to accept that he had to find a workaround for the problem. "With this survey we did not have the luxury to say that the skies are not looking so great this morning so let us fly in the afternoon," he said. "If we were lucky, we may have got half an hour of clear skies on rare occasions, but for the most part it was heavy clouds all day, every day. We could have waited for months and still not seen a whole day without dense cloud cover."

"Our plan was to fly at an altitude of around 3,000ft (914m) above ground level (AGL)," Munceanu continued. "We recognized early on that the presence of the clouds would not allow us to stick to our flight plan. Once in the air, we would have to adjust the altitude depending on the altitude of the cloud. I figured if we stayed at the base of the cloud with varying adjustments of on average 300ft below the 3,000ft mark, we would be able to achieve the necessary results."

For traditional sensors with fixed field of view (FOV), reducing the flight altitude in this way would have been a major challenge because the swath on the ground would get narrower, potentially creating gaps between flight lines that could be a basis for the client to reject the survey data. Instead, the operator would

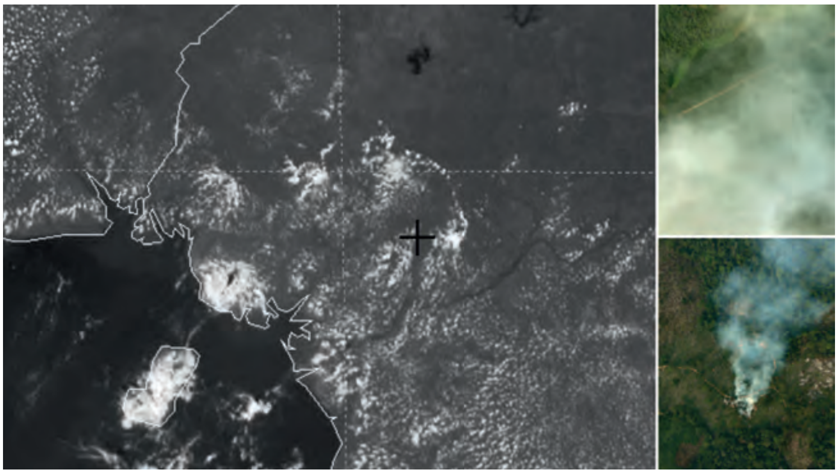


*Figure 2: Meteosat HRV image of the cloud cover around the survey area (pixel size: 1km), with white speckles indicating large clouds that prevent a clear view of the land. Inset images show cloud cover over the area and the smoke caused by bush fires*

need to compensate for the narrow swath by packing the flight lines closer together – resulting in more flight lines, more survey time and more cost. STI, however, had a better option. "What helped us immensely was the Teledyne Optech PRIME's SwathTRAK feature," said Munceanu. "This allowed us to keep a regular swath on the ground even when we varied from our flight plan."

## DYNAMIC FIELD OF VIEW TO THE RESCUE

To keep the Lidar's swath consistent, the feature constantly monitors the GNSS and IMU data to determine whether the aircraft is deviating from the flight plan. Such deviations can include both the aircraft's position (too high, too low or too far to the side of the flight line) and its orientation (too much roll, pitch or crabbing). It also constantly monitors the range to the ground reported by the Lidar to determine whether the elevation of the ground itself is changing. By combining this position/orientation and ground elevation data, the feature can calculate whether these factors are distorting the swath on the ground and adjust the scanner's FOV accordingly.

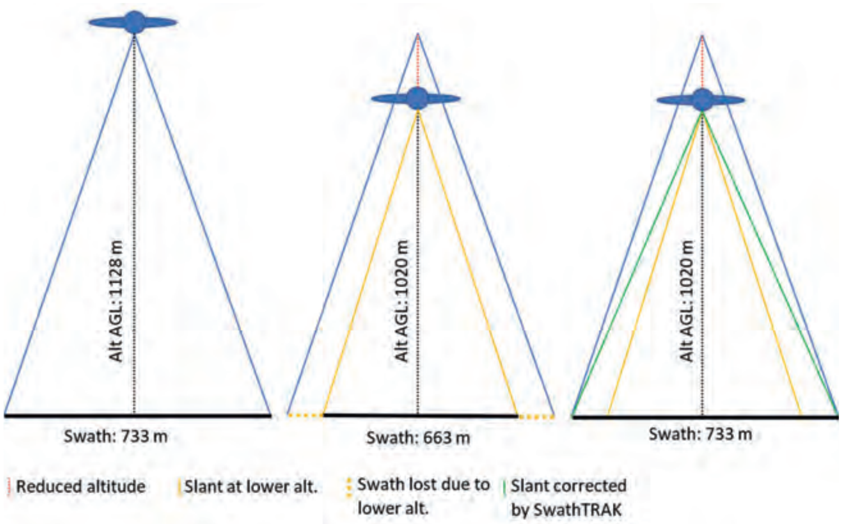
Teledyne Optech originally designed SwathTRAK for high-relief terrain, where it could increase the FOV when flying over hills and reduce the FOV when flying over valleys, thereby keeping the swath at a constant width and improving operational efficiency and data consistency. Over the years, however, the feature has been further developed to handle many other conditions such as corridor mapping applications. In this case, STI realized that this solution could also compensate when the aircraft itself (not the ground) was changing elevation. Thus, when the aircraft had to fly lower due to clouds, the FOV was widened to keep the width of the swath on the ground steady and avoid gaps between flight lines (see Figure 4). Notably, despite the reduction in altitude from 1,128m to 1,020m AGL, the operator was still able to get the full swath of 733m as the FOV expanded to achieve the planned coverage. Thanks to this flexibility, the STI team did not have to replan based on ever-changing weather conditions since they were guaranteed that the sensor would deliver the planned swath width and density even if they had to fly lower than planned.

## SUCCESSFUL RESULT DESPITE THE CLOUDS

In practice, STI planned the surveys normally, setting the flight altitude to maximize productivity and cost efficiency, resulting in a 200-hour project. During each survey, the STI field crew (pilot and operator) adjusted their altitude to fly just below the cloud ceilings, relying on SwathTRAK to automatically compensate for the reduced altitude. That said, the operator did need to work within the hard limits of the technology during the flight planning phase. For this feature, the maximum scanner compensation is ±10° from the planned FOV, with a hard limit of ±30° from nadir (the Galaxy's maximum FOV being 60°). For example, if the nominal FOV used is ±25° (a 50° full FOV), only ±5° is left for compensation. If the nominal FOV is ±20° (a 40° full FOV), the full ±10° can be utilized for compensation. Lastly, this solution only works for the Lidar, not the camera. Flying lower than planned still slightly decreased the footprint of the camera images on the ground, which could conceivably cause gaps between them. To avoid this, STI planned for plenty of sidelap between images.

On average, the cloud cover forced STI to fly about 380ft (120m) below the planned altitude, and as much as approx. 560ft (170m) lower on Douala's cloudiest days. Without dynamic FOV, STI would have consistently lost up to 20% of flight lines every mission and would have spent a sizeable amount of time on replanning and post-processing to avoid/explain issues

*Figure 3: View from the survey aircraft showing thick cloud cover above.*




▲ *Figure 4: An example of an original flight plan (left), a reduced flight plan due to cloud cover (centre) and an actual swath thanks to the expanded FOV shown in green (right) – not to scale.*

related to gaps and reduction in coverage rate. With dynamic FOV, the operator did not have to waste time remaking the flight plan each morning and the analyst was able to streamline the data, which was of consistent coverage and density.

Despite the challenges posed by the clouds, the team flew every planned flight while maintaining the desired point density and an average absolute accuracy of 8cm off of ground control. STI's client, who had accompanied the team on one of the flights and was familiar with the challenges posed by the local weather conditions, was very happy when presented with the final results. According to the team's own estimate, without the flexibility of using SwathTRAK it would have taken twice the time and effort to complete the project. Ultimately, the Galaxy PRIME's built-in feature enabled the project to be completed on schedule and on budget, despite the cloudy conditions. ◀

### ABOUT THE AUTHOR

**Sumona Datta** started her career as a journalist in Mumbai, India. She has since been associated with the Lidar industry for over two decades and is currently the media relations and content creation manager for Teledyne Imaging.
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*Cyclomedia collaborates with Hexagon to create first-of-its-kind photorealistic 3D model of an entire country*

# 3DNL – The Netherlands from Every Angle

Smart digital realities that replicate real-life geoinformation provide valuable insights and support the analysis and interpretation of infinite data inputs from the real or digital world. They can be used to improve work processes and planning for commercial and government customers. 3DNL is a first-of-its-kind photorealistic digital twin of the entire Netherlands. It is based on airborne imagery and Lidar data, collected with a Leica CityMapper-2 aerial sensor and made accessible through Cyclomedia's Street Smart web viewer hosted on HxDR, Hexagon's cloud-based storage, visualization and collaboration platform.

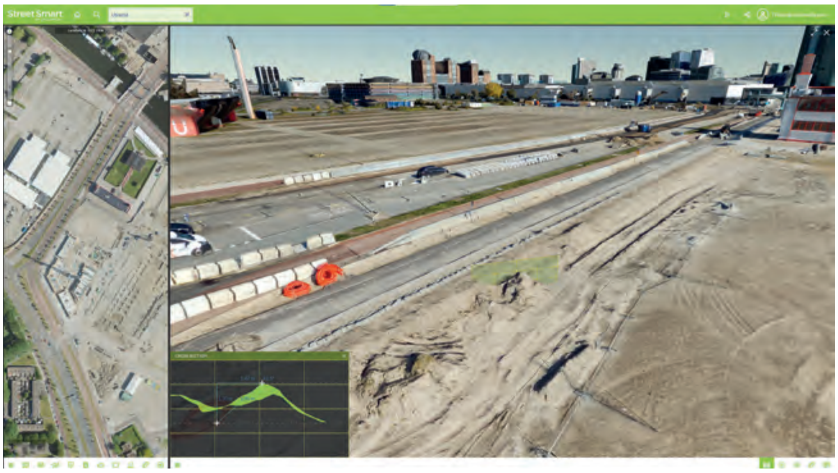
**3D DIGITAL REALITIES ARE CHANGING THE GAME**

Cyclomedia has provided 360-degree street-level visualizations, collected with a patented vehicle-mounted camera, for decades. Since 2018, a Lidar sensor has been added to the proprietary mobile mapping system. These comprehensive ground-based data sets enable the extraction of light poles, manholes and an array of other features, providing insight for many municipal management and planning applications and other commercial activities.

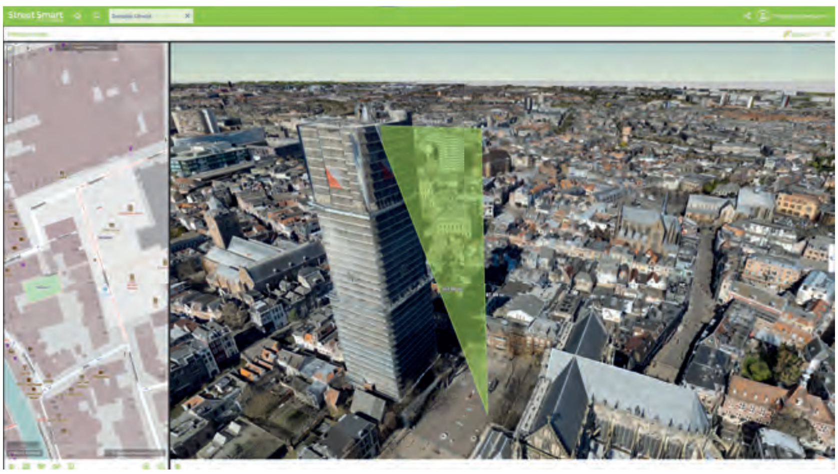
Aware of the increasing demand for 3D data and wanting to maintain its position as a preferred aerial content supplier, Cyclomedia recognized the benefits of creating an innovative hybrid data set, offering both price and product delivery advantages. By creating 3DNL, the company has produced a multipurpose digital twin. As well as its direct use in Street Smart, the 3D data can also be streamed or downloaded for use in third party applications.

"We are making a big impact by creating a new way for customers to interact with data and develop insights to create smarter cities, achieve more efficient construction, and derive information from the data to provide knowledge," says Thomas Pelzer, product manager, Cyclomedia. "The Netherlands is our primary market for making a photorealistic 3D model with an aerial perspective and for testing the market's response to this new proposition."

Leica CityMapper-2, the state-of-the-art hybrid airborne sensor, is perfectly suited for efficient and accurate urban mapping. The simultaneous acquisition of oblique imagery and Lidar point clouds produces perfectly registered consistent data. The narrow field of view minimizes occlusions while the oblique scan pattern captures building facades from all angles. One flight instead of two reduces the environmental impact, decreases the cost of data acquisition, and takes advantage of limited flying windows. However, the most important benefit of using a hybrid system lies in the quality of the data products. Image-only systems struggle to provide accurate data in shadows, urban canyons and under vegetation. The Lidar



▲ *3DNL cross section measurements of construction site.*



▲ *3DNL distance and height measurements.*

▲ *3DNL mesh of the Old Church in Delft.*

▲ *3DNL mesh of Utrecht railway station.*

data perfectly complements image data to fill the gaps. As an active sensor, it does not require light to create accurate data points and can provide returns from underneath vegetation. At the same time, the image data is crucial for the generation of textured 3D models. A hybrid sensor provides more information, more accurate measurements and smoother surfaces in the mesh.

"Adding a Lidar sensor to an oblique camera, as found in the Leica CityMapper-2, is a game changer. We have a strong preference for hybrid data and there are many advantages to joining forces on acquisition and development with a large global corporation such as Hexagon," says Pelzer. "We are always looking for new ways to bring best-in-class products to market and Hexagon shares our enthusiasm for innovation."

## UNMATCHED 3D MESH QUALITY

To capture the Netherlands in its entirety under favourable conditions, Cyclomedia partnered with Hexagon to capture aerial data each year between February and October and produce the best data set possible. After processing with Leica HxMap software, the aerial imagery and Lidar data as input was converted into a mesh and added to 3DNL. The 3D data is hosted on HxDR and fully integrated in Street Smart. HxDR


▲ *Leica CityMapper-2 hybrid airborne sensor.*

enables the geospatial data and software to be visualized by users worldwide.

"The geometrically accurate 3D maps and models within 3DNL can be used in many applications by utilizing Street Smart's functionality," says Chantal Brick, marketing manager, Cyclomedia. "HxDR adds flexibility by working with us to accommodate Cyclomedia's technical needs."

Cyclomedia's Street Smart viewer provides a simple way to access the hosted data set and includes a visualization tool plus other key features and functionality such as shade analysis, BIM models, cross-sections and measurements. It also supports the virtual collaboration of project stakeholders in any field.

The high-quality 3DNL data set is instantly available to users. Cyclomedia provides customers with access to the complete comprehensive 3D database through a subscription. Therefore, the data is not only virtually accessible, but also economically accessible to anyone with a need or desire to work with 3D data. The product is certainly less expensive than contracting a custom collection and 3D mesh creation.

## PRACTICAL APPLICATIONS

Hexagon and its partners have made great strides towards creating a digital environment in which stakeholders and citizens can plan, visualize and simulate developments. Tasks such as importing CAD and BIM data, importing reality capture data, automesh of reality capture data, virtual tours and flythroughs, annotations and photosphere locations are possible.

The broad range of applications appeals to government and commercial customers. For example, a solar company may download the model of a specific house, calculate the pitch and slope, create a solar plan and present a proposal to the house owner.

Construction and engineering companies can download an area of interest, design a new build and determine the most efficient access and logistics for the construction phase. A governmental agency may calculate how many trees are in a neighbourhood and plot heat pockets and perform shade analysis.

"There is great value in being able to visualize every aspect of a new structure and seeing how it fits with existing features before beginning construction," explains Brick. "For example, local citizens can see how a wind turbine will look and better understand its impact on the community while working through the approval process."

The collaboration of Cyclomedia and Hexagon on this groundbreaking 3D digital twin project demonstrates the potential for the large-scale simultaneous collection of imagery and point clouds with the Leica CityMapper-2.

"We envision 3D to be part of a solution to accommodate users in a variety of work processes that need highly accurate data, as we offer through reality capturing," says Pelzer. "We're continuing to improve on the quality of both the input and the output data, and to leverage the classification of the point clouds to identify objects in the mesh models. By producing multi-use data sets, a variety of sectors such as local government, construction and engineering, infrastructure, and wind and solar energy all benefit from better information. Our long-term goal at Cyclomedia is to expand into other geographic areas with 3D, while a next milestone will be to systematically combine aerial and street-level content." ◀

**MORE INFORMATION**
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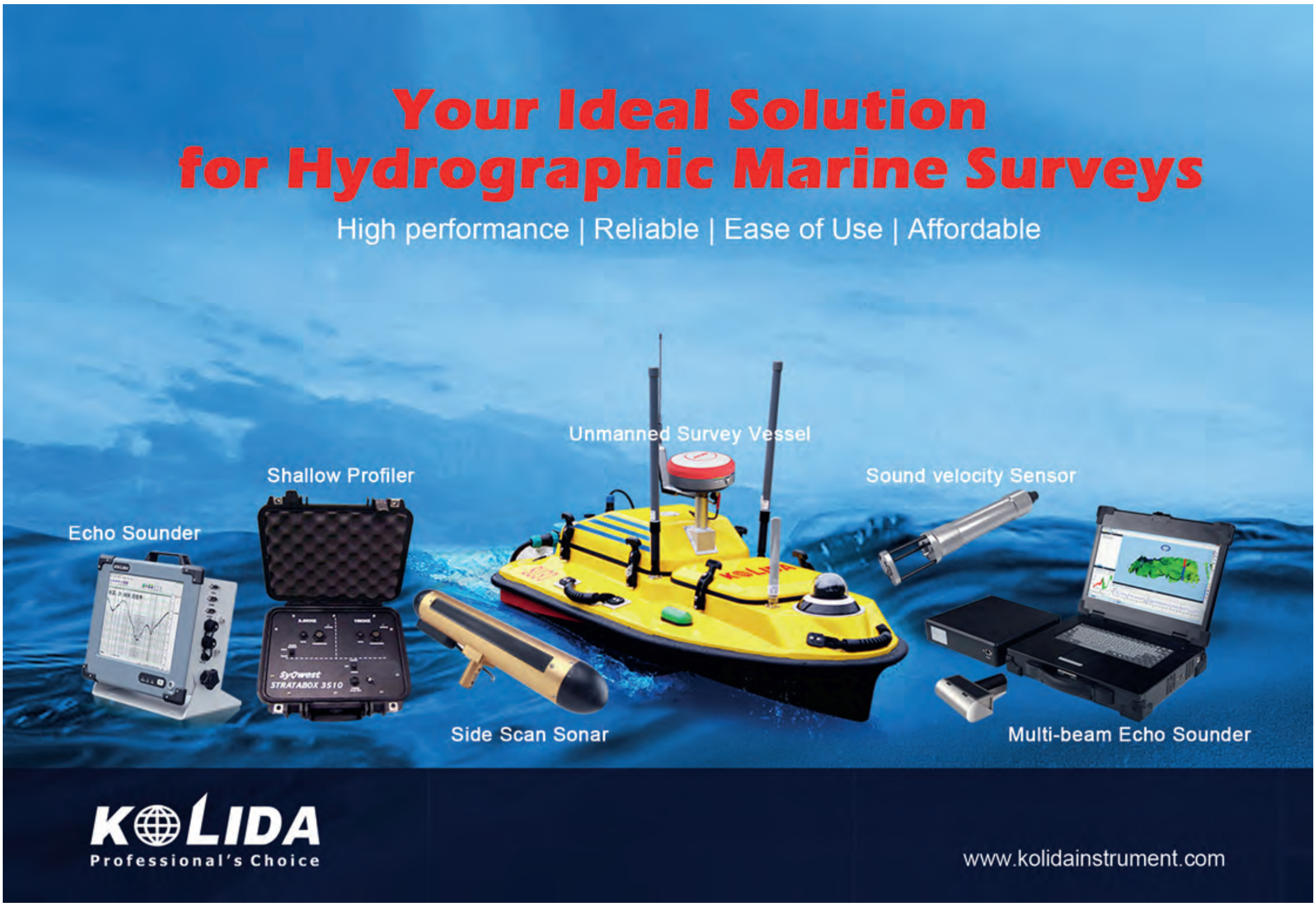
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*THE BENEFITS OF PROGRESS IN UAV AND LIDAR SENSOR TECHNOLOGY*

# Underwater Deadwood and Vegetation from UAV-borne Topobathymetric Lidar

The monitoring of submerged deadwood and vegetation is gaining increased attention due to their socio-economic and ecological importance. Deadwood acts as an important underwater habitat but also poses a threat to bridges, hydroelectric power plants and riverside buildings. Underwater vegetation, in turn, is a proxy for climate change in general and global warming in particular. In this context, UAV-borne topobathymetric laser scanning constitutes a promising tool for accurately capturing and modelling these small-scale objects in high spatial resolution.

Alluvial forests surrounding natural rivers constitute an ecologically important and sensitive habitat. Seasonal flood waves carry deadwood into the active river channels, where it floats downstream until either natural or artificial barriers (river bends, bridge piers, hydropower stations, etc.) stop its movement. Such stranded driftwood plays an important role in aquatic ecosystems, for example as a shelter for juvenile fish stages, but log jams can also damage infrastructure and residential areas. In addition to deadwood, the monitoring of littoral vegetation (i.e. submerged vegetation down to a depth where sunlight can penetrate to support photosynthesis) is gaining ever more interest, as such vegetation acts as a proxy for climate change. Submerged macrophytal vegetation reacts in a very sensitive way to increased water temperature and other parameters induced by global warming. Therefore, the monitoring of the volume and distribution of driftwood in rivers and lake outlets and of littoral vegetation is an important topic from both an ecologic and socio-economic point of view.


▲ *Figure 1: RIEGL VQ-840-G topobathymetric laser scanning system mounted on Skyability Octopcopter UAV in front of Pielach River study area.*

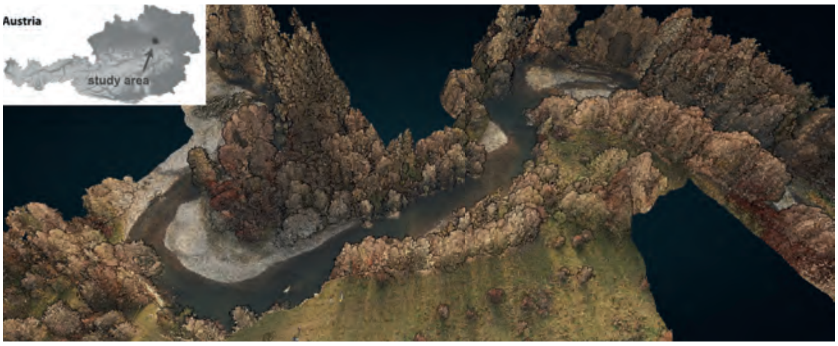
## GAME CHANGER

Topobathymetric Lidar is an established tool for mapping the littoral zone of coastal and inland water areas. Bathymetric Lidar uses short laser pulses in the green domain of the electromagnetic spectrum to measure objects above and below the water table. Compared to topographic sensors that use infrared laser radiation, bathymetric sensors employ a large beam divergence, which results in typical footprint diameters in the range of about 50cm for data acquisition from manned platforms. This, however, hampers the detectability of submerged logs and branches, especially for stem diameters of less than 30cm. The advent of UAV-borne topobathymetric Lidar sensors has changed this situation fundamentally, as these systems provide small laser footprint diameters of around 10cm and a high laser pulse density of > 200 points/m$^2$.

In this article, we present the early results of detecting and modelling submerged driftwood and vegetation based on 3D point clouds acquired with a survey-grade UAV-borne topobathymetric laser scanner. We demonstrate that stems, branches and littoral vegetation are recognizable in the point cloud. The achievable point density and measurement precision furthermore allow the derivation of relevant parameters such as the length and diameter of driftwood logs and the vegetation height of macrophyte patches. This enables the quantitative analysis of submerged biomass at a high spatial resolution.

## SENSOR

The RIEGL VQ-840-G is an integrated topobathymetric laser scanning system including a factory-calibrated IMU/GNSS system and a camera, thereby implementing a full airborne laser scanning system (see Figure 1). The lightweight, compact VQ-840-G Lidar can be installed on various platforms, ncluding unmanned aerial vehicles (UAVs or 'drones'). The laser scanner comprises a frequency-doubled IR laser, emitting pulses




▲ *Figure 2: Pielach River study area; 3D topobathymetric Lidar point cloud coloured with simultaneously acquired aerial RGB images.*

of about 1.5ns pulse duration at a wavelength of 532mrad and a pulse repetition rate of 50-200kHz. At the receiver side, the incoming optical signals are converted into a digitized electrical signal. The laser beam divergence can be selected between 1–6mrad to allow a constant energy density on the ground for different flying altitudes and therefore balancing eye-safe operation with spatial resolution. The receiver's iFOV (instantaneous field of view) can be chosen between 3 and 18mrad. This allows the balancing of spatial resolution and maximum depth penetration.

The VQ-840-G employs a Palmer scanner that generates a nearly elliptical scan pattern on the ground. The scan range is 20° x 14° along the flight direction, which means that the variation of the incidence angles hitting the water surface is low. Onboard time-of-flight measurement is based on online waveform processing of the digitized echo signal. In addition, the digitized waveforms can be stored on disc for offline waveform analysis. For every laser shot, echo waveform blocks with a length of up to 75m are stored unconditionally (i.e. without employing prior target detection). This opens up possibilities such as waveform stacking, variation of detection parameters or waveform analysis algorithms. The depth performance of the instrument has been demonstrated to be in the range of more than two Secchi depths for single measurements.

## STUDY AREA AND DATASETS

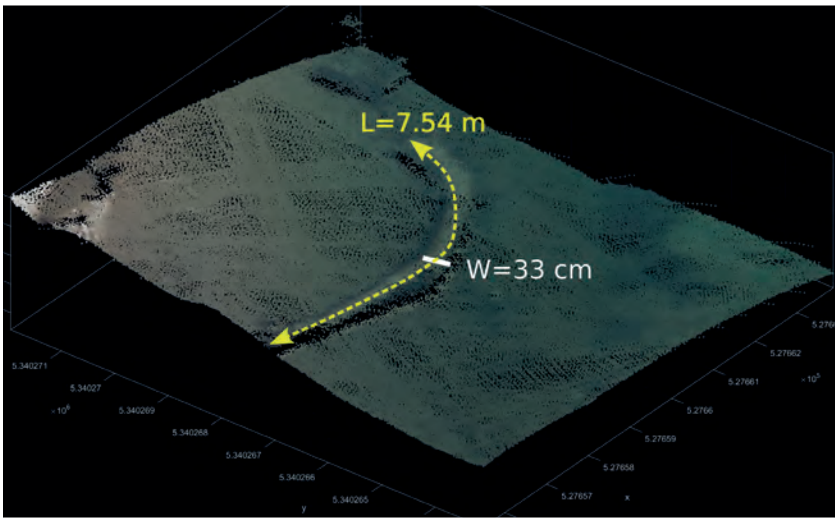
The study area is located at the tailwater of the pre-Alpine Pielach River, a tributary of the Danube River in Lower Austria. The study site is located in a Natura 2000 natural conservation area and the gravel bed river features a meandering course with frequent geomorphic changes in response to flood peaks. The mean width of the river is around 20m with a mean annual discharge of 7m³/s and a maximum depth of around 3m, allowing full coverage of the entire river bottom with topobathymetric Lidar. Alluvial vegetation (trees, bushes, shrubs) often reaches from the shore into the wetted perimeter, leading to the frequent input of wooden debris into the river. In addition, larger flood peaks transport driftwood logs from upstream into the study area, where the logs often remain for a longer period before drifting further downstream with the next flood peak.

The subsurface of the adjacent flood plain is dominated by river gravel, which was quarried in the past, leaving around a dozen groundwater-supplied ponds with a maximum depth of 5.6m and featuring patches of underwater vegetation. The occurrence of complex bathymetry as well as the presence of submerged driftwood and littoral vegetation makes the site an ideal study area for UAV-borne topobathymetric Lidar.

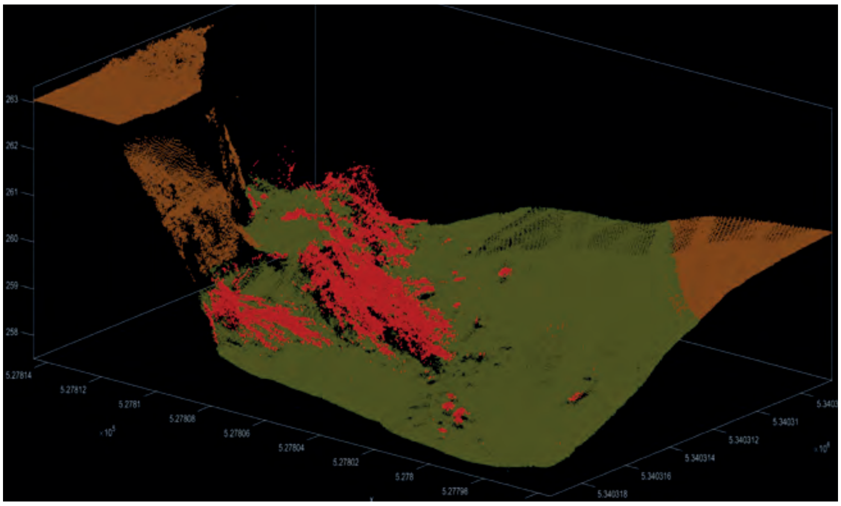
The area has been surveyed twice with the RIEGL VQ-840-G in the recent past. In November 2021, the scanner was mounted on an octocopter UAV operated from 50-60m above ground level with a beam divergence of 1-2mrad, providing footprint diameters of around 1dm, and with a pulse rate of 50kHz and 200kHz. A simultaneous UAV-based photogrammetry flight mission served as a basis for colouring the Lidar point cloud (see Figure 2). In February 2022, the same instrument was mounted on a helicopter platform. While the aim of the UAV-borne acquisition was maximum spatial resolution to detect submerged logs and branches, the focus of the helicopter integration was to maximize the penetration depth. For this reason, a larger beam divergence of 5mrad was used together with a receiver FoV of 9mrad, delivering full bottom coverage of the surveyed ponds alongside additional vegetation heights.

## METHODS AND RESULTS

The processing pipeline mainly followed the standard bathymetric Lidar workflow. After strip alignment and georeferencing, we modelled a continuous water surface model from all air-water interface Lidar reflections and performed run-time and refraction corrections of the raw measurements. The corrected points served as the basis for deriving the DTM (bare ground + submerged bottom). In addition, the volumetric point density of all remaining water column points enabled automatic classification of the underwater vegetation. Visual analysis revealed two categories of submerged vegetation: (i) single broad tree stems and (ii) bunches of smaller branches and vegetation patches.




▲ *Figure 3: 3D point cloud of submerged driftwood stem coloured by RGB.*



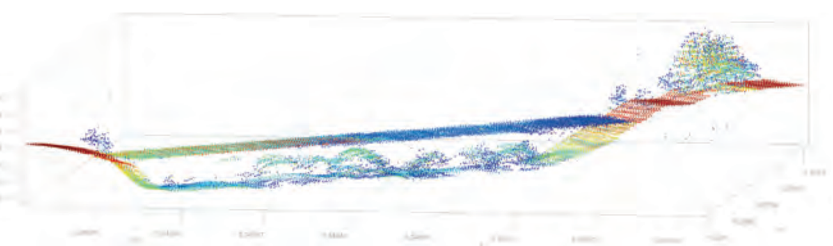
▲ *Figure 4: 3D point cloud of submerged bunch of willow tree branches coloured by class ID (red).*

Figure 3 shows a 3D point cloud of a large individual stem coloured by RGB and Figure 4 features many thin branches of an entire willow tree coloured by classification. Both examples prove the feasibility of (i) detecting and (ii) automatically classifying underwater vegetation from UAV-borne topobathymetric point clouds. The length and width of the stem in Figure 3 are 7.54m and 33cm respectively. In contrast to deadwood in dry forests, submerged driftwood is often sparser and the absence of understorey facilitates detection. On the other hand, forward scattering of the laser signal underwater leads to blurring of the point clouds, which complicates the automatic detection of dense small structures (branches) and the precise estimation of vegetation patches due to progressive broadening of submerged driftwood point clouds with increasing water depth. Patches of submerged macrophyte vegetation are shown in Figure 5.

## CONCLUSIONS AND OUTLOOK

Progress in UAV and Lidar sensor technology is enabling the capture of submerged topography and the detection of complex features such as deadwood and submerged vegetation in high detail. UAV-borne topobathymetric sensors featuring laser beam divergences of ~1mrad operating at an altitude of approx. 50m provide sub-decimetre laser footprint diameters. Together with high pulse repetition rates of 200kHz and slow flying velocities of 5-6m/s, this results in point densities of more than 200 points per $m^2$, and thus very high spatial resolution. Furthermore, sensors featuring user-definable beam divergence, receiver's field of view and scan rate make it possible to balance depth performance and spatial resolution.

Based on the automatic classification of 3D points, it is now possible to quantify parameters of submerged deadwood (stem length and width) and littoral vegetation (vegetation height and volume). Further improvements to the processing pipelines are subject to future research. The focus is on gaining a better understanding of the interaction of green laser radiation with water and multiple small-scale objects within the laser's line-of-sight to improve established full-waveform processing techniques to handle these complex target situations. Other topics of interest include improving the automatic classification of submerged driftwood, vegetation and the water bottom, the segmentation of individual deadwood logs, the characterization of littoral vegetation, and the independent accuracy assessment of derived metrics. ◀



▲ *Figure 5: 3D topobathymetric Lidar point cloud coloured by reflectivity (blue: -30dB, red: -10dB) showing patches of macrophyte vegetation.*


### ABOUT THE AUTHORS

**Gottfried Mandlburger** studied geodesy at TU Wien, where he also obtained his PhD in 2006. After completing a three-year research position at the University of Stuttgart (2017–2019), he returned to TU Wien in 2020, where he is currently working as senior researcher and lecturer in the Photogrammetry research division within the Department of Geodesy and Geoinformation. In November 2021, he obtained his venia docendi (post-doctoral qualification) in Photogrammetry for his thesis on Bathymetry from Active and Passive Photogrammetry. His main research areas are airborne topographic and bathymetric Lidar from both manned and unmanned platforms, multimedia photogrammetry, bathymetry from multispectral images, DTM modelling, topographic data management and scientific software development.

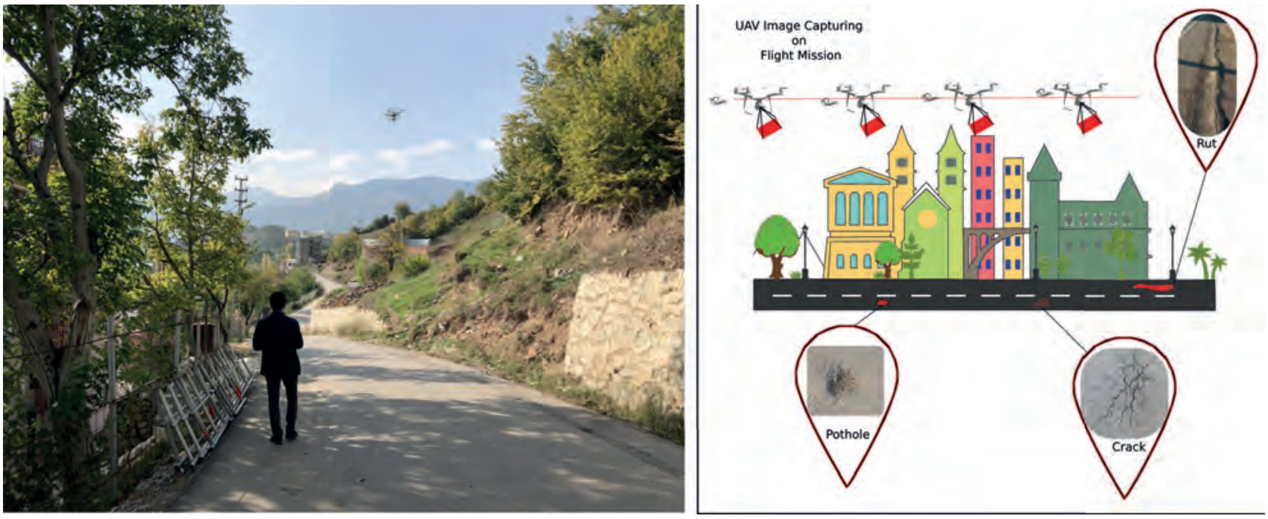
**Martin Pfennigbauer** holds a PhD in electrical engineering from Vienna University of Technology. He has been employed by RIEGL Laser Measurement Systems since 2005, presently as chief research officer. His special interest is the design and development of Lidar instruments for surveying applications, with a focus on rangefinder design, waveform processing and point cloud analysis.

**David Monetti** holds a DI from TU Wien. He is currently CEO at Skyability GmbH, a drone service provider based in Austria. He manages daily business and research projects funded by Austrian national funds. His product development activities focus on Lidar systems; using Lidar on platforms such as ULS, MLS or TLS have turned it into a tool used daily which now creates the best obtainable digital twin of a target of interest. For more than a year, David has also been responsible for implementing Lidar bathymetry at Skyability. His research activities and more than five years of hands-on work have made him a true expert in the field.

*THE BENEFITS OF AIRBORNE TECHNOLOGY IN URBAN PROJECTS*

# Automated Extraction of Road Information from UAV-based Data

When it comes to monitoring the condition of roads, UAV technology can overcome many of the downsides associated with traditional methods, which can be time-consuming, labour-intensive and sometimes subjective. This article explores the opportunities for automated extraction of UAV-based data information about road construction, inventory and road environments.




▲ *Figure 1: UAV-based data collection and inspection of road condition.*

Roads are one of the significant urban characteristics. They connect long distances to each other effectively, quickly, comfortably and safely. Therefore, their current conditions need to be monitored to make sure they meet the standards. However, traditional methods to monitor the condition of roads are time-consuming, labour-intensive and sometimes subjective. A relatively new way to monitor road condition is unmanned aerial vehicle (UAV or 'drone') technology. UAVs are one of the fastest-growing technologies in several fields such as precision farming and agriculture, forest, ecological and structural health monitoring, and geological, topographic and archaeological mapping.

UAV-based data is collected as the UAV flies over the study area and captures multiple images. Two different types of flight plans, namely manual and autopilot flight plans, are available in the UAV remote controller. Both plans have their own advantages. The autopilot flight plan is straightforward to collect data. The flight plan is remotely set in the interface and the UAV flies and acquires data automatically. However, the flight plan needs to be adjusted according to the characteristics of the UAV platform, which are maximum flight time, flight speed, height above ground level and horizontal distance.

## ACQUIRING, PROCESSING AND VIEWING UAV DATA

The autopilot flight plan may not be suitable due to the harsh terrain or conditions of the study area, such as having steep slopes or having overhead powerline cables and poles, structures or trees. In these cases, manual flight may be better for safety reasons. In addition, two different kinds of images – nadir and oblique images – can be captured using UAV technology (see Figure 1). Oblique images increase the three-dimensional (3D) model quality, especially on vertical structures. The camera on the UAV is another important component to collect high-quality data, and camera specifications directly affect the quality of the captured images. The resulting two-dimensional (2D) images can be used to monitor road conditions. However, they may not support accurate surveying since single images provide no depth information.

3D models can also be produced from 2D images. Most UAVs usually contain global navigation satellite system (GNSS) and inertial measurement unit (IMU) sensors, which provide camera locations with centimetre-level accuracy. Therefore, the 3D model can be produced using structure from motion (SfM) techniques. The SfM technique finds tie points in each image that can be matched on consecutive images. In addition, camera locations and orientations are also estimated using photogrammetric equations. Lastly, 3D point clouds of the object of interest can be reconstructed. There are several user-friendly commercial software options (Pix4D Mapper, Agisoft Metashape, 3D Survey, UASMaster, Photomodeler, etc.) and open-source software (VisualSFM, MicMac, COLMAP, etc.) to

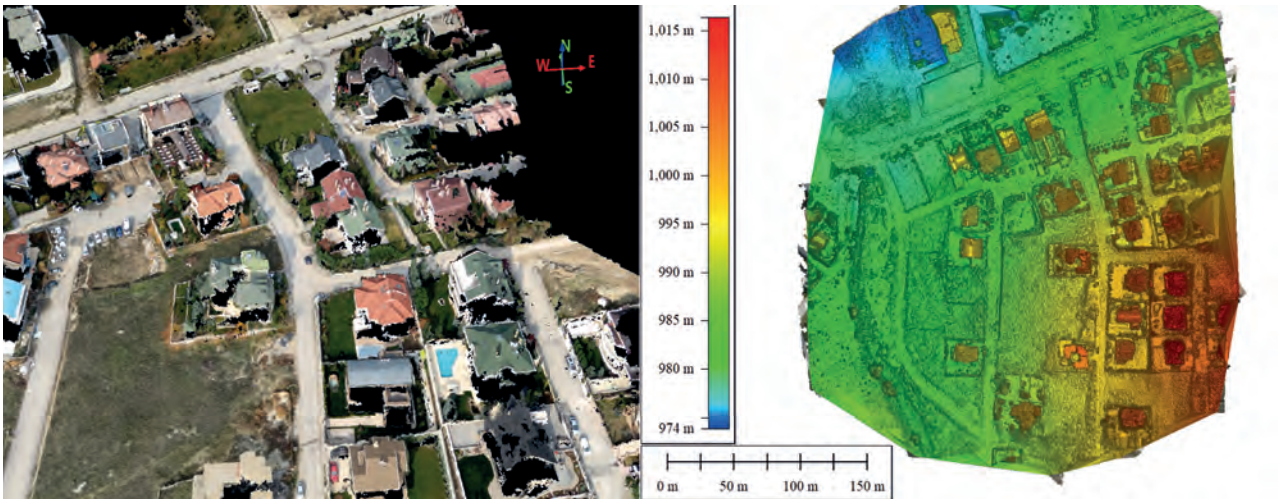



*Figure 2: 3D point cloud in Quick Terrain Modeller and DSM in Global Mapper.*

convert 2D images into 3D point clouds using SfM techniques. In addition, orthomosaics, digital surface models (DSMs) and digital terrain models (DTMs) can be produced using such software. These outputs can be viewed using various software such as Quick Terrain Modeller and Global Mapper (see Figure 2).

## EXTRACTING ROAD INFORMATION

Road information such as road surface, centre line and lane markings, profile, cross-sections and distresses can be extracted from 3D point clouds. These insights into road condition are significant for improving road performance, comfort and safety. In order to collect road information, the road surface first needs to be distinguished from other urban or rural objects and classified. Machine learning algorithms such as Random Forest can be used to classify road surfaces, and these algorithms produce classification results both quickly and with high accuracy. Once the road surface has been classified, other geometric information can be easily extracted.

Road centre line and lane markings are commonly used for road modelling, planning and safety. In addition, this information will be increasingly important for navigation purposes, especially in the context of autonomous driving in the near future. If the road lanes are marked using a specific colour (mostly white or yellow), they can be directly extracted using the RGB feature. RGB values express the colour of the 3D model, and they are transferred from the image processing software using images. In some cases, especially on local roads, road lanes may not be marked in a specific colour or the road lane markings may be damaged and not continuous. In such cases, several methods – such as the improved Voronoi diagram-based algorithms – can be introduced to extract the road centre line and lane markings more robustly and accurately.

'Road profile' refers to the vertical section taken along the alignment axis (centre line) of the road. It is important to analyse the incline of the road since this can be a source of danger in the case of icing. Road profiles can be extracted through the DSM. DSM data

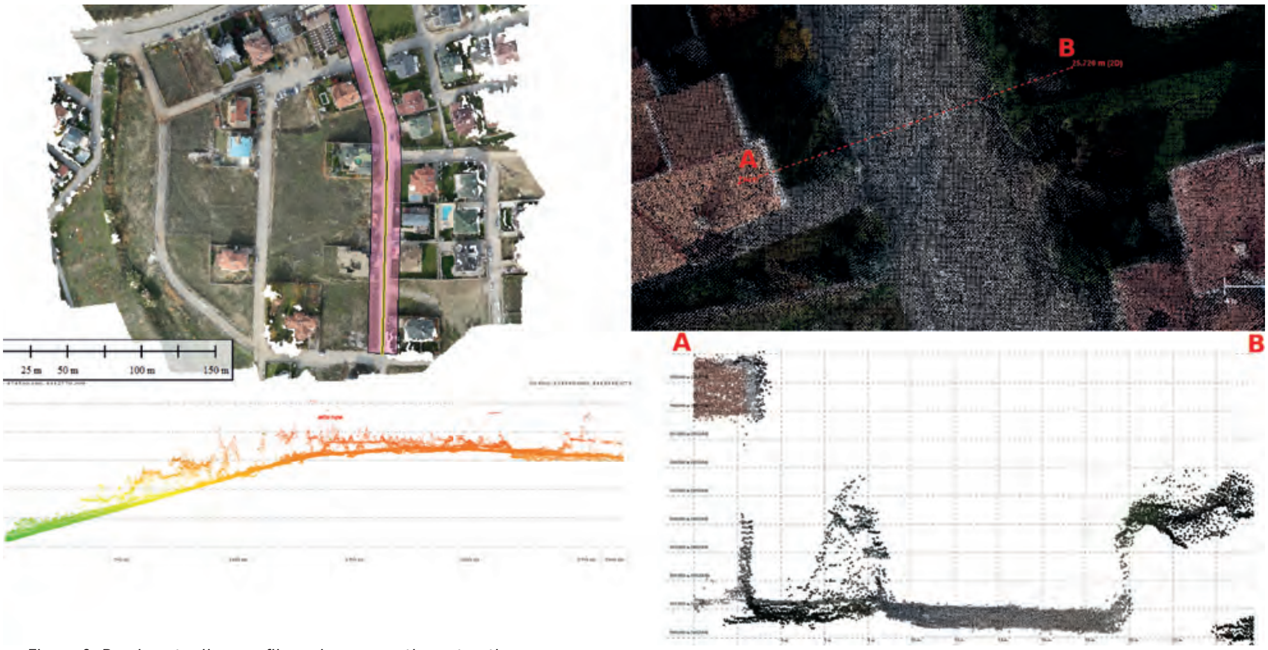



*Figure 3: Road centre line, profile and cross-section extraction.*

can be produced from 3D point clouds using various interpolation algorithms. One of the most commonly used interpolation algorithms is the inverse distance weighted (IDW). The height values are recorded as a raster format in the DSM. Then, the Z dimension of the road centre line is extracted from DSM to obtain the profile of the road easily and accurately (see Figure 3).

The road cross-sections provide the creation of a road platform with certain slopes perpendicular to the road centre line. The cross-sections are also important for the transfer of water from the road surface to the roadside and the design of the drainage channels alongside the road. Similarly, the Z dimension of the lines perpendicular to the road centre line is extracted from DSM to obtain the cross-sections of the road easily and accurately (see Figure 3). Lastly, road distress can also be detected from 3D point clouds. Accurate detection of road distress is an important input for maintenance and repair actions. Timely maintenance and repairs need to be performed to increase the road's service life, and to maximize comfort and road safety for drivers. In addition, on-time maintenance and repairs may reduce long-term costs. Various methods and techniques are capable of automatically detecting road distress.

## CONCLUSION

Besides being used in other disciplines, UAVs have great importance in surveying and producing all kinds of up-to-date road information. In particular, the use of UAVs in road projects has increased in recent years since they can play an important role in the control of road inventory and safety, repeated land surveys and analysis of sustainable road networks, and mapping and projecting activities. Automated information extraction is very effective with small-package software as well as traditional GIS software. As a result, it is possible to extract information about road construction, inventory and road environment from UAV-based data. It is inevitable that, in the near future, the use of UAV systems will secure its place as an indispensable measurement method in road construction and the production of other road information. ◀


### *ABOUT THE AUTHORS*

**Dr Mustafa Zeybek** received his doctorate in 2017. He is currently the head of the Department of Architecture and Urban Planning at the Güneysınır Vocational School of Selcuk University in Turkey and is a faculty member. The main research areas are UAV, mobile Lidar, terrestrial laser scanning, deformation measurements and analysis, point cloud processing, forest measurements and road surface distress analysis.

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**Dr Serkan Biçici** is an assistant professor in the Engineering Faculty of the Department of Geomatics Engineering at Artvin Coruh University, Turkey. He received his MSc and PhD degrees in civil engineering from The Ohio State University. His research interests cover various topics, including transportation planning, the traditional travel demand model and its statistical mode. His latest research focuses on road surface and geometric extraction, and road distress analysis.

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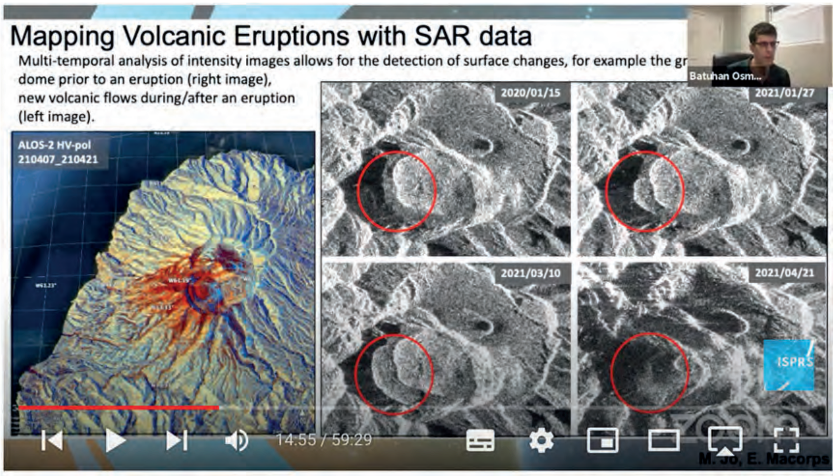
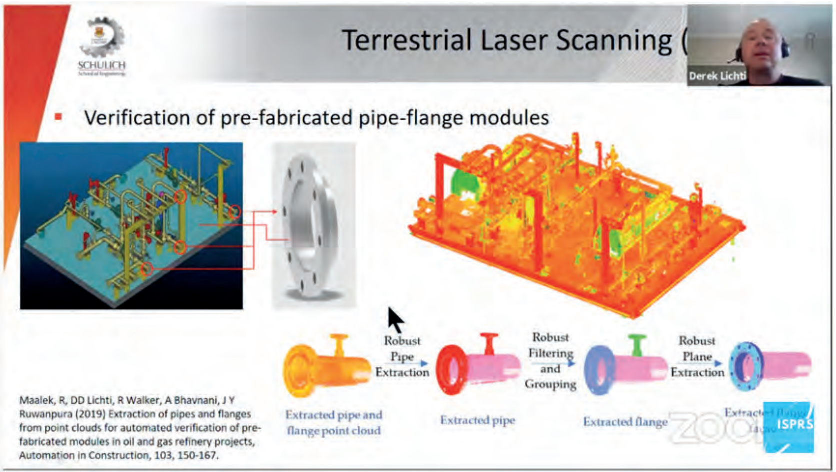
# Diversity and Inclusion on the Agenda




▲ *Since April 2021, under the newly launched Virtual Keynote Speaker Series, webinars have been held regularly free of charge.*

The short description of the International Society for Photogrammetry and Remote Sensing (ISPRS) says that "the Society is a non-governmental organization devoted to the development of international cooperation for the advancement of photogrammetry and remote sensing and their applications". One of the many ways to fulfil this definition is to encourage the organization of scientific meetings. To support this activity and strengthen cooperation with its members, the ISPRS Council decided to help organizers of scientific meetings to achieve better visibility of their events by introducing the Keynote Speaker Series. The series offers financial support for keynote speakers at such events.

The ISPRS Keynote Speaker Programme provides an opportunity for ISPRS Ordinary Members (OdM), Associate Members (AsM) and Regional Members (RgM) to support events organized under their umbrella by inviting top-quality international experts, in order to attract more participants and enhance the scientific quality of the event. The programme was launched in 2019 and three organizations were able to make use of this possibility before the COVID-19 restrictions were imposed. However, when many ISPRS events were forced to be cancelled in 2020, and a few of them held virtually, the programme was interrupted.

The ISPRS Council decided to enlarge this service in a new direction, as did many other organizations, and began to present latest advances related to various important topics in webinar format. Since April 2021, under the newly launched Virtual Keynote Speaker Series, webinars have been held regularly free of charge.

The following list shows that the webinars cover very interesting themes related to topical issues in photogrammetry, remote sensing and geospatial sciences:

- Deep learning for global vegetation analysis (Jan-Dirk Wegner)
- New network design processes to support 3D reality capture with terrestrial laser scanners (Derek Lichti)
- Capture and interpretation of mobility data (Monika Sester)
- Human cognition and visuo-spatial information: Experiments in visualization and virtual reality (Arzu Çöltekin)
- All you ever wanted to know about the ISPRS Congress in Nice 2022 (Christian Heipke, Nicolas Paparoditis)
- Golden age of SAR? (Batu Osmanoglu)
- Photogrammetry in allied health: Two applications (Petra Helmholz)
- Geospatial information extraction from EO images using deep learning approaches (Costas Armenakis)
- Creating digital twins of cities: from data acquisition to 3D modeling and analyses (Bruno Vallet).

These webinars were attended by many participants who actively participated in consequent discussions.

ISPRS invites interested scientist, experts, students and suchlike to take part in or attend future webinars. Details of upcoming sessions are available on the ISPRS website. All ISPRS members, including Individual Members, receive emails informing them about the webinars.

*Lena Halounova, ISPRS Secretary General*

**More information**
https://www.isprs.org/society/ksp/default.aspx

# New Leadership in FIG Africa Regional Network

The FIG Council has appointed Mohammed Mamman Kabir from Nigeria as the new chair of the FIG Africa Regional Network (ARN) for the coming term, with immediate effect. Mohammed Mamman Kabir has been in and around FIG for many years and is an active member of ARN. He is known as a tireless promoter and supporter of young surveyors in Africa, and in 2019 he represented the Africa region at a FIG strategy seminar.

There will be a transition period during the coming months between Jennifer Whittal, the current chair of ARN, and Mohammed Mamman Kabir. Jennifer Whittal took over the leadership from FIG Vice-President Diane Dumashie for the 2019-2022 term in 2019. Under her leadership, ARN has continued to develop and grow and is today a vibrant network with many activities, exciting undertakings and ideas for future development. The latest initiative is a mentoring programme in Africa.

Jennifer Whittal had expressed her interest to continue. However, in view of her academic profile, the FIG Foundation and FIG Council wished to see her become director of the FIG Foundation, and it is not possible to continue in both positions at the same time. Whittal has kindly accepted to become one of the FIG Foundation directors, although she also expresses her sorrow at leaving ARN.

Once the FIG Council decided to appoint Jennifer Whittal, it was the wish of the FIG Foundation that she should take over as soon as possible. This means that Whittal has actually already been appointed and installed as director. She has promised to continue with ARN for some time to ensure a smooth transfer to the new chair of ARN.

The FIG Council thanks Jennifer Whittal for her extensive work to continue the growth of ARN over the past three and a half years. Having a strong network in Africa is a true strength for FIG. The FIG Council is also certain that this development will continue with Mohammed Mamman Kabir at the helm during the next term.

**More information**
www.fig.net

# Obituary: Lynn Usery

On 22 March 2022, the world lost a GIS giant and cartography compadre when Dr Lynn Usery, current chair of the ICA Commission on Map Projections and former ICA vice-president, passed from this earthly plane. Less than a week earlier, Lynn had been busily planning workshops for AutoCarto 2022. He will be sorely missed by ICA and our community, not only for his many research contributions, leadership, vision and tireless service, but also for his friendship and camaraderie.

Michael Tischler of the U.S. Geological Survey (USGS) wrote: "On paper, we knew him as the director of the Center of Excellence for Geographic Information Science (CEGIS). But he was far more than that title would lead one to believe. Lynn leaves a remarkable legacy given his extraordinary scientific accomplishments, presence as a leader in the geographic science community and impact on individual geographic scientists inside USGS and around the world."

It's a challenge to specify the impact that Lynn has had on the field of GIScience because of the breadth and depth of his involvement and contributions. He was centrally involved in many areas of the discipline, including cartography, GIS, remote sensing and spatial analysis. His eclectic research interests included digital cartography, map projections, scale and resolution, image classification, temporal GIS, geospatial semantics and ontology, and high-performance computing for geospatial data. It would be difficult to name a subject in our field about which Lynn could not speak knowledgeably and insightfully.

Lynn was unique in that his impact came through his careers in both government and academia. Lynn started working for the USGS in 1977. He was a cartographer and geographer for the USGS from 1978 to 1988 focusing on developing automated cartographic production systems. In 1988, he took on a geography faculty position at the University of Wisconsin (UW) – Madison. In January of 1994, he moved to Georgia to serve on the geography faculty at the University of Georgia (UGA). In May of 1999, Lynn took on a position as research geographer with the USGS in addition to his academic job at UGA. In 2005, he returned to USGS and ultimately conceived and became director of CEGIS. In this role, he directed the science programme and the visions and plans for topographic mapping research. While at USGS, Lynn also taught remote sensing at the Missouri University of Science and Technology.


In all his positions, Lynn was a groundbreaker. In his early days at USGS, he began the development of digital mapping systems for the automated production of printed topographic maps. At UW, he helped found a GIS programme. At UGA, he helped establish certificate programmes in GIScience at both the undergraduate and graduate levels. When he returned to USGS, he started a cartography research programme that led to CEGIS. For CaGIS, he chaired AutoCarto 2005 to close an eight-year gap and resurrect the symposium series. He also spearheaded the effort to bring the International Cartographic Conference back to the USA for only the second time, the first being in 1978.

That Lynn was so involved in the association is admirable. That he did the same with many other societies, at the same time, makes Lynn exceptional and unparalleled. There is truly no match for him in this regard, and really not even anyone in the running. No other person has been elected vice-president of the ICA, president of the Cartography and Geographic Information Society (CaGIS), president of the American Society for Photogrammetry and Remote Sensing (ASPRS), and president of the University Consortium for Geographic Information Science (UCGIS), as Lynn was in 2015, 2002, 2004 and 2015, respectively. Additionally, as with the ICA, in all these associations, he also served in other roles. On a personal note, Lynn was born in December 1951. He had two children, a son Kelynn, born 1986, and a daughter, Lacy, born 1988. Lynn received his BSc in geography from the University of Alabama and MA and PhD degrees in geography from UGA. He died on Tuesday 22 March 2022, after a brief illness.

*Tim Trainor, President of ICA*
*Aileen Buckley, US national representative to ICA*

**Lynn was involved in multiple activities of the ICA:**

| | |
|---|---|
| 2004-2008 | US National Committee to the ICA Member |
| 2007-2011 | ICA Map Projections Commission Secretary |
| 2007-2015 | US National Committee to the ICA Chair |
| 2011-2012 | ICA Technology Outreach Working Group Chair |
| 2011-2015 | ICA Map Projections Commission Vice Chair |
| 2011 | Bid for ICC 2017 |
| 2012-2017 | ICC 2017 Conference Organizer |
| 2015-2019 | ICA Vice President |
| 2018-2019 | ICA Body of Knowledge for Cartography Working Group Chair |
| 2019-2022 | ICA Map Projections Commission Chair |

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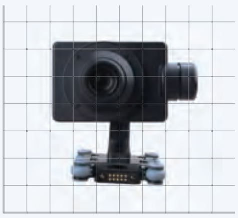
C20 Basic Camera



C50 Optional Camera

LiAir VH2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