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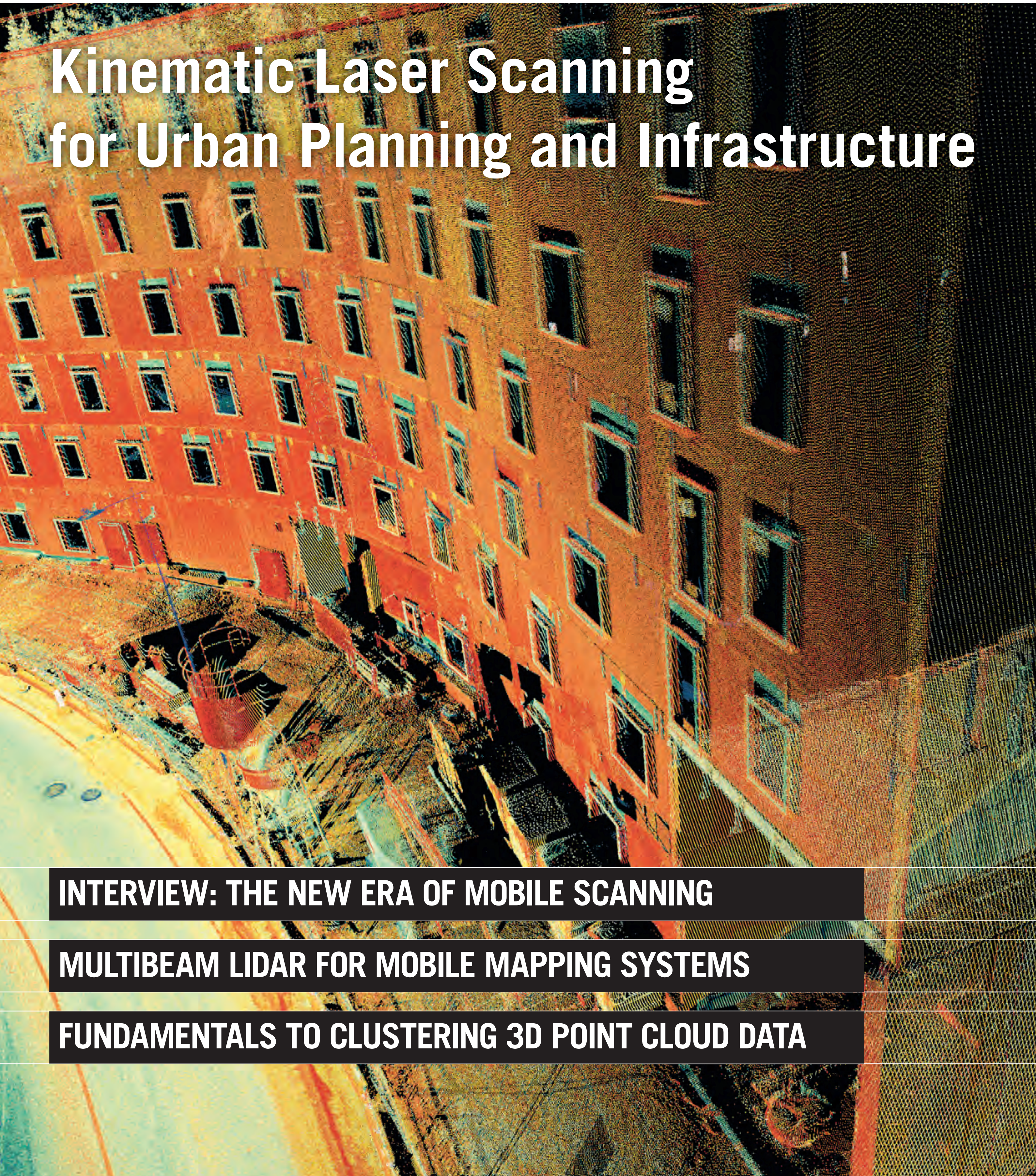

Kinematic Laser Scanning for Urban Planning and Infrastructure

INTERVIEW: THE NEW ERA OF MOBILE SCANNING

MULTIBEAM LIDAR FOR MOBILE MAPPING SYSTEMS

FUNDAMENTALS TO CLUSTERING 3D POINT CLOUD DATA

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COVER STORY

The cover image is a site of a new apartment building. Kinematic 3D data allows not only quick documentation of the construction phase, but also a means to monitor the land use, terrain shaping and drain elevations, and to inspect the building foundation level and placement of the construction versus the permit and city plan. **Read more on page 31**

Leitmotif

Traditionally, Germany is the heart of the geospatial industry at this time of the year, with Intergeo taking place in either September or October. The annual trade fair and conference is a major gathering of mapping and surveying professionals from all around the world. Due to the coronavirus outbreak, everything is different this year, and Intergeo is being held digitally from 13-15 October. For me, it feels almost surreal to not be travelling to Germany for the industry highlight of the year, not be meeting with experts from so many different companies and hearing about their inspiring contributions to innovate the industry, and not be raising a glass with fellow members of the geospatial industry at many of the informal get-togethers and side events.

However, as you will notice in this bumper-packed September/October issue of *GIM International*, Germany remains a powerhouse within the geospatial industry. Recently, Esri announced the acquisition of nFrames, a company that started as a spin-off of the University of Stuttgart. Today, nFrames has become a high-end developer of photogrammetry software technology for large-scale mapping applications, and Esri will now integrate its SURE software into the company's ArcGIS platform. We couldn't let this moment pass unnoticed, and so on page 59 you will find a Q&A with Richard Cooke, Esri's director of imagery.

Another German company that was established as a spin-off (of the University of Munich) is NavVis. Within just a couple of years, NavVis has evolved into a leader in digital twin technology. Its mobile and wearable mapping systems have changed the indoor mapping landscape. Although the company's technology was originally designed for indoor use, its mobile mapping solutions are now also being used outdoors on a large scale. We had the opportunity to interview Felix Reinshagen, co-founder and CEO of NavVis, and I strongly recommend that you read the resulting article in which he shares his vision. "Sophisticated 3D scanning devices can produce point clouds and images which are so realistic and so easy to implement that they eliminate the need for modelling altogether," is just one of the many forward-looking excerpts from the interview. As we can see on pages 10-13, even Chancellor Merkel seems to be impressed by their multi-sensor mobile scanning technology!

Yes, digital technology is the leitmotif here, simply because the future – needless to say – is digital! From that perspective, a virtual meeting place bringing together geospatial experts from all over the world makes perfect sense. But let's be honest… the importance of face-to-face contact – also in business life – should not be underestimated. Technology simply can't replace some human interactions. Therefore I sincerely hope that Intergeo 2021 can be held physically – perhaps in a hybrid form – in the future, in the country that can safely be described as the cradle of many innovations in the surveying and mapping profession.

Wim van Wegen,
content manager

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Taken for granted

This is the first time in months that I am sitting at my desk and putting some words on paper for this magazine. Due to the COVID-19 crisis, we cancelled the summer issue of *GIM International* – something we never imagined would happen, but with so many flights grounded and air cargo capacity severely reduced it suddenly became extremely difficult to get a printed version of *GIM International* to all our readers. This crisis reminds us just how much we've taken smooth-running global logistics – amongst many other things – for granted in recent decades. It turns out that shipping a magazine all over the globe isn't so easy after all. Needless to say, I am very happy that, in many parts of the world, things are gradually getting back to normal (although, even as I write this, I realize that the situation could take a turn for the worse in a matter of weeks or even days… let's hope not!).

This edition of *GIM International* highlights the increasing importance of Lidar in many policymaking and decision-making processes. One of Lidar's advocates is James Van Rens, senior vice president of Riegl USA, who has written this month's Industry Insight (see page 24) titled 'The Future of Lidar is Critical to the Future of Our World'. That is quite a bold statement, but I have to agree with him. The geospatial market has matured over the past decades and quite a few of the technologies coming from our industry are now underlying fundamentals for policymakers – and Lidar is certainly one of them. The dashboards monitoring the spread of coronavirus in the current pandemic are just one example. More specifically, satellite data revealed the 'greening' of Earth during the economic shutdown, not only underlining the need to work towards a sustainable future for our planet but also showing that it is possible to turn the tide of destruction.

Two examples of that 'greening' stuck with me: the view of the Himalayas from the northern parts of India, from where people hadn't seen the mountain range for years due to smog, and the aquatic life swimming in the clear blue waters of Venice's canals again following years of pollution caused by hordes of tourists in gondolas and water taxis. Both these examples of the positive side effects of the pandemic, along with many more, show that we should strive even harder to support the recovery of nature once the virus outbreak is behind us.

At this time of the year, many of us are usually getting ready to travel to Germany for the biggest show in geomatics, Intergeo – but not this year, unfortunately. However, the organizing team have done an impressive job to serve up a large and comprehensive virtual edition of Intergeo for industry professionals. I encourage you to take a look at www.intergeo.de and gain wonderful new insights and experiences. In the meantime, I hope we will be able to meet each other again in person in Hanover for the 2021 edition of Intergeo in order to catch up on the latest news, exchange views and enjoy heartfelt reunions. Until then, stay safe and healthy – and happy reading!

P.S. Check out the revamped *GIM International* website for daily news, opinions, articles, videos and much more to come: www.gim-international.com.

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Esri Acquires nFrames to Prioritize 3D Capabilities

▲ *nFrames' SURE software will become part of Esri's ArcGIS platform.*

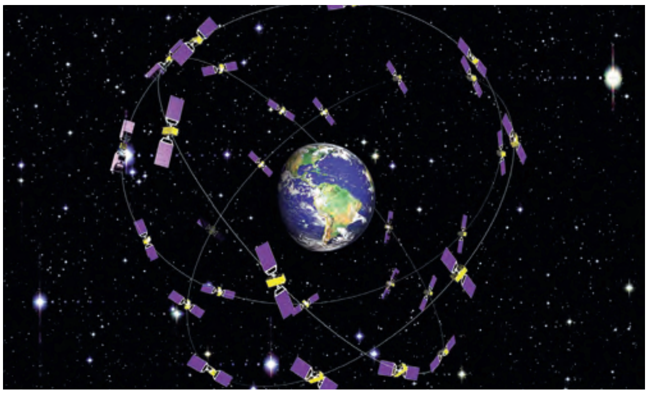
Esri has announced its acquisition of nFrames, a German technology company that develops SURE, an industry-leading imagery and Lidar 3D surface reconstruction software. This will enable the fusion of imagery with 3D GIS, allowing nFrames and Esri users to seamlessly capture and analyse 3D data from aerial, drone and ground-based sensors in an automated end-to-end process. SURE scales 3D data creation to large city and countrywide airborne image datasets and projects, while giving professional photogrammetry workflows improved precision, speed and simplicity on premises or in the cloud. Through this acquisition, Esri gains a robust production engine that transforms imagery and Lidar data into point clouds, photo-textured 3D meshes and true orthos. Users in government, urban planning or architecture, engineering and construction (AEC) can use SURE to generate 3D maps at scales from individual construction sites to entire cities and countries.

▶ **Full story here: https://bit.ly/3iCAq11**

Galileo Next-generation Satellites on the Horizon

With 26 satellites now in orbit and over 1.5 billion smartphones and devices worldwide receiving highly accurate navigation signals, Europe's Galileo navigation system is moving towards the next generation of satellites, ensuring quality services over the next decades. Following the European Commission's decision to accelerate development of Galileo Next Generation, ESA has asked European satellite manufacturers to submit bids for the first batch of the Galileo Second Generation (G2) satellites. The new spacecraft are expected to be launched in about four years. The next-generation satellites will provide all the services and capabilities of the current first generation, together with a substantial number of improvements as well as new services and capabilities.

▶ **Full story here: https://bit.ly/32xLIn5**



▲ *Galileo constellation. (Image courtesy: DLR)*

4 Earth Intelligence Launches Countrywide Satellite Intelligence Data

▲ *Multi-use image of Addis Ababa, combining (from top left to bottom right) Points of Interest & Landcover, Raw Imagery, and Wealth Index. (Image courtesy: 4EI, Mapbox, OpenStreetMap)*

Earth observation company 4 Earth Intelligence (4EI) has launched a suite of data layers providing insight into a country's wealth, demographics and transportation links. Derived from satellite imagery and other reputable resources, including the World Bank, Open Street Map, census records and historical archives, the Country Intelligence data suite has been created to support economic analysis, policymaking and SMART Sustainable Development Goals (SDGs) reporting. "Satellite imagery records what is happening on the planet rather than what is being reported and so is the perfect resource, when combined with multiple, validated data sources, to provide off-the-shelf resources for countrywide intelligence on economic and societal health," commented David Critchley, CEO of 4EI. "Whilst each layer has enormous potential to inform the creation of adaption strategies – including the delivery of SDGs – and emergency responses, the true potential of the Country Intelligence suite is released when the layers are used in combination."

▶ **Full story here: https://bit.ly/3iNXoCN**

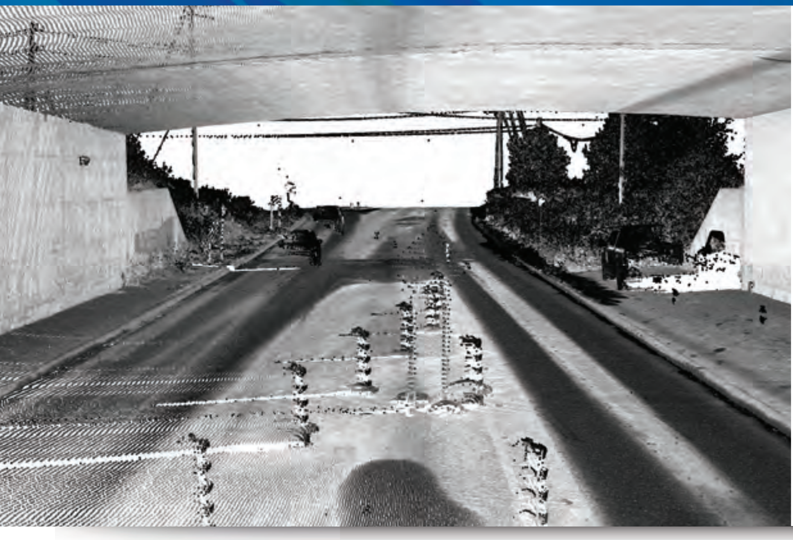
Microdrones Enters the Third Dimension with New Mapping and Drone Lidar Surveying Equipment

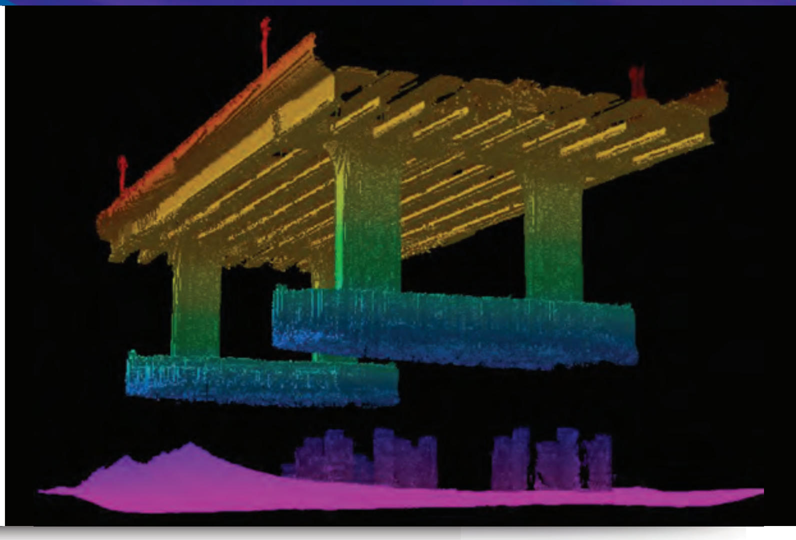
▲ *Microdrones enables users to acquire 3D imagery data.*

Microdrones has used the recent months to launch the Microdrones as a Service (mdaaS) business model as well as next-generation system features. The company now aims to continue innovating and delivering new technology, and is introducing four new survey equipment systems. "Customers have been looking for ways to acquire 3D and oblique imagery data, and we wanted to offer fully integrated systems, software, workflow, maintenance and support for these applications," explained Vivien Heriard-Dubreuil, Microdrones CEO. "In addition, we are proud to present a new survey-grade Lidar system that can capture data from greater flight altitudes or extremely detailed data from lower altitudes."

▶ **Full story here: https://bit.ly/3iBy3f8**

THE WORLD IN 360 DEGREES





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This program is undertaken with the financial support of the Canadian Space Agency.

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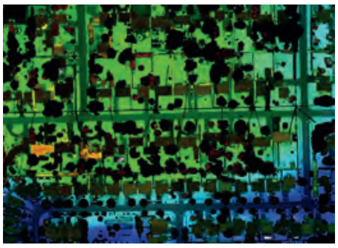
Teledyne Optech Launches Airborne Lidar Sensor for Corridor Mapping



▲ *The CM2000's small footprint allows for complete detection of thin distribution wires.*

Teledyne Optech, a Canada-based advanced Lidar sensors company, has extended its Galaxy line-up to include the CM2000, a new sensor specifically designed for corridor mapping. With a true measuring rate of up to two million points per second, the Galaxy CM2000 delivers precise detail of fine corridor elements such as electric wires and conductors, distribution power poles, railway signs and cellular tower antennas, as well the ability to detect fine changes in the ground over time for pipeline monitoring. The CM2000's adjustable field of view provides users with the flexibility to narrow it to the exact width of their corridor and therefore concentrate the laser measurements on their precise target. This combination of an adjustable field of view and a measurement rate of two million points per second makes it possible to deliver data resolution that allows for advanced analytics, insights and decision-making.

▶ **Full story here: https://bit.ly/2GYN4cQ**

OGC Welcomes Microsoft to the OGC Community as a Principal Member

OGC® Making location count.

The Open Geospatial Consortium (OGC) has welcomed Microsoft to the OGC as a Principal Member. As such, Microsoft will participate in OGC activities and serve on OGC's Planning Committee to explore market and technology trends relevant to OGC's global mission of making location information more Findable, Accessible, Interoperable and Reusable (FAIR). "We are excited to welcome Microsoft back to the OGC community, and to the OGC Planning Committee, as an OGC Principal Member," said OGC CEO Nadine Alameh. "These are pivotal times in the geospatial industry as OGC collaboratively modernizes our suite of location standards to enable the seamless integration of location information into any application. It's great to see Microsoft's commitment to standards and interoperability in creating location-aware applications for the world."

▶ **Full story here: https://bit.ly/3kknXj9**

Trimble Adds New Innovation to Flagship GNSS Solution

▲ *Trimble R12i GNSS receiver.*

Trimble has introduced the Trimble R12i GNSS receiver, the latest addition to its global navigation satellite system (GNSS) portfolio. The Trimble R12i incorporates inertial measurement unit (IMU)-based tilt compensation using Trimble TIP technology, which enables points to be measured or staked out while the survey rod is tilted. This empowers land surveyors to focus on the job at hand and complete work faster and more accurately. The IMU-based tilt compensation capability of the Trimble R12i builds on Trimble's highly regarded ProPoint GNSS positioning engine which, according to the company, delivers more than 30% better performance in challenging environments compared to the Trimble R10-2 receiver across a variety of factors, including time to achieve survey precision levels, position accuracy and measurement reliability. The Trimble ProPoint is designed with flexible signal management that enables the use of all available GNSS constellations and signals, providing new levels of reliability and productivity. In addition, the ProPoint engine is a key enabler of the new TIP technology. Surveyors can continue to use the R12i's tilt compensation functionality, even in challenging environments when other solutions struggle to maintain GNSS and inertial positioning.

▶ **Full story here: https://bit.ly/3kkoiCr**

EuroGeographics Pledges Support for UN-GGIM Focus on Authoritative Geospatial Data

▲ *EuroGeographics President Colin Bray (left) with the association's secretary general and executive director, Mick Cory.*

EuroGeographics has welcomed the intention of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) to focus on issues concerning authority, custodianship and legal issues for data for the public good. The association, which represents Europe's national mapping, cadastral and land registration authorities, has pledged to support the UN-GGIM Working Group on Legal and Policy Frameworks in its aim to better understand the definition and importance of authoritative data. It is also offering access to its extensive network to help gather examples of best practice and to facilitate information sharing. Mick Cory, secretary general and executive director of EuroGeographics, said: "The critical importance of trusted geospatial information to support decision-making at all levels and many areas of national and international concern is demonstrated by the current COVID-19 pandemic. However, there remains insufficient awareness of the importance of good-quality data in addressing global challenges and addressing national and global economic and social goals."

▶ **Full story here: https://bit.ly/3mpbFb2**

GIM INTERNATIONAL INTERVIEWS FELIX REINSHAGEN, CEO OF NAVVIS

The New Era of Mobile Scanning

Indoor mobile mapping is well past the tipping point and is about to go mainstream. Felix Reinshagen is co-founder and CEO of NavVis, a company that was set up with the objective of bridging the gap between outdoor and indoor digital maps. In this interview he shares his views on the future, including his confidence that there will be plenty more developments in automatically generated assets from reality capture and how 3D scanning and the geospatial industry are set to impact the world in many respects.

Do you see laser scanning becoming a commodity in the near future, or will it remain a specialist job with large equipment? And how is NavVis preparing for that future?

When it comes to the sheer availability and amount of laser scanning that's being done, it will certainly become a commodity. But we'll also see a broader sweep in the quality of laser scanning being carried out, and it will be very specific to the different jobs and their requirements. For example, there will be lower-accuracy laser scans conducted by people with smaller, less expensive devices and with less of a technical background. But at the same time, there remains a need for high-quality and very precise laser scans. That will stay a specialist job for the foreseeable future, even though it will also be made easier and faster using tools that do part of the quality assurance semi-automatically. One of the core technologies to make things easier is SLAM (*simultaneous localization and mapping, Ed.*), where part of the registration of different datasets is done automatically and where you have better guidance and tools like quality maps and graphical user interfaces to better support users throughout a project. But the same technology isn't limited to SLAM-only devices; it's also in mixed devices, which we can see in laser scanning equipment that use auto-registration and self-levelling. In terms of how is NavVis is preparing for this future, we're setting the pace. We were one of the first to introduce SLAM-based scanning devices that really extended the range of areas where SLAM could be used. In the past it was generally tied to only low-quality scans. We've made SLAM much more accurate, so it can serve a much wider segment of the industry, and we've put a lot of effort into usability and integrating the scanning workflow with the traditional surveying workflow. For example, use of our SLAM anchors (aka ground control points) still requires some specialist knowledge but it's a lot faster and alleviates some of the difficulty, plus you can do it with less qualified personnel. The real expertise in the future will rely on two things: first, knowing and deciding what kind of equipment you need, and then combining different ways of scanning to deliver more comprehensive data which at the same time has exactly the right quality

▲ *Felix Reinshagen presenting at the NavVis Summit in Munich in 2019. (Photo: Mathis Beutel)* at the perfect cost point. Today we see a lot of over-delivery of quality, with excessive cost, file sizes and level of detail, and that's not necessarily a good fit either.

What are the main challenges in obtaining larger and more accurate point clouds, and how is NavVis tackling them?
For surveyors or laser scanning professionals using a terrestrial laser scanner to create very large and highly accurate point clouds, the challenges are that the scanning process is very slow and a massive amount of data is being generated. A terrestrial laser scanner (TLS) just doesn't scale very well. The solution we're offering is a next-generation SLAM-based mobile mapping device that is capable of sub-centimetre accuracy, is much more scalable, and takes a fraction of the time to complete a job. The time advantage of SLAM-based devices will kick in depending on the number of square metres that need scanning. The benefits aren't immediately apparent for just one room, but if you've got to scan five floors or even five buildings, then the advantages of SLAM-based scanning will quickly accumulate. That's scalability. Besides making SLAM more accurate, it's also extremely helpful that we can tie our mobile mapping devices in to more traditional surveying methods. We can incorporate ground and wall anchors, so you can guarantee a baseline quality to your measurements and adjust the quality to the job requirements. If you really want to do a very simple scan with only local accuracy in a small environment, then you might not need SLAM anchors at all. If you want large, high-quality point clouds, then it's the ability to sync up advanced SLAM-based devices with ground control points that makes our technology so unique.

How will you use the recently received new funding to further develop the company?
The additional €20 million in funding provided by the European Investment Bank comes at the right time, when the SLAM-based scanning market and the digital twin market are rapidly expanding. We'll use it to double down on the continued development of our core technologies and further build our global presence.

What are the main challenges in mapping indoor and other GNSS-denied environments?
The difficulty in mapping GNSS-denied environments is that you don't have an absolute reference, so you need to have another means of creating very reliable or accurate reference points indoors. You'll need a SLAM device that's either a lot more stable and provides more accuracy in an order of magnitude, or you'll need a device that's capable of tying into measurement points that were projected into the GNSS-denied area for higher accuracy. Our scanning hardware is capable of both; our devices are very resilient against drift, much

▲ *NavVis CEO Felix Reinshagen showcased NavVis technology to Chancellor Merkel and Minister President Söder of Bavaria during their visit to the Technical University of Munich. (See also picture on page 12)* more so than other SLAM devices on the market, and they can tie into these projected reference points.

Now that you have gone from a large cart to a more mobile set-up, what's the next step in laser scanning?
From my point of view, there are a couple of directions which are inevitable. One will be a greater importance of software than hardware. Over the lifetime of the NavVis M6, for example, it became a lot more accurate and a lot cleaner in data quality than when it was first launched, and we've delivered a couple of nice additional features in terms of usability. We're already setting the quality standard for dynamic mapping, but you can expect to see similar additional improvements in data quality and usability over the lifetime of NavVis VLX. Even further down the line there will be further advances in miniaturization, and SLAM-based scanning in general will become much more mainstream, occupying a much larger market share. It won't entirely replace other forms of scanning, but we believe it will be the dominant form in the long term as devices become smaller and easier to operate. They'll also provide more intuitive feedback – for example, the right moment to make a loop closure and so on – making laser scanning more convenient and accessible for non-specialists and allowing laser scanning to conquer many new fields, workflows and verticals.

Sensor technology is making systems smaller and smaller. How is this impacting on your laser scanning systems?
Sensors are certainly getting smaller, and they're becoming more affordable too. Although the accuracy of these smaller, lower-end sensors hasn't really improved so far, we can reasonably assume that they'll catch up in this respect as well. In the future you'll have better and cheaper sensors which are smaller than today, powered by more advanced software. You'll be able to build devices that are at least as good as the best of today's SLAM-based devices, but they'll be even more affordable – today the cost is largely still driven by the cost of sensor technology – and they'll have smaller form factors. Perhaps the bigger question is whether high-end laser scanning technologies are going to make the leap onto a smartphone or tablet, because if they move do then you'd potentially have a scanner with you at any time. But I don't see that happening just yet, because even solid-state Lidar requires a lot of energy, and I don't think that there's a viable use case for the average person needing the capability to conduct large, very accurate scans.

What about outdoor scanning? Do you see a role for NavVis there?
NavVis technology was originally designed for indoor use, because indoor mapping at scale really was an unsolved problem. We started from the assumption that 10cm accuracy in the first-generation NavVis M3 was adequate for mapping. But after we mastered that, our customers then requested the same speed and cost but with survey-grade quality. This gap has been mostly closed and we've learned, to our surprise, that NavVis M6 and NavVis VLX are being heavily used outdoors. This is somewhat of a new development because we've traditionally positioned our devices for indoor scanning, but what we're seeing is that the same quality is really appreciated for outdoor use cases as well. Innovative customers of ours are scanning outdoors not just between buildings, but also moving into applications like forestry and topography.

How do you make sure your Lidar solutions are user friendly and accessible for a broad audience of experts from different backgrounds?
We believe in user interfaces that are accessible and intuitive, and that's where all our scanning devices are really pioneers in their field. You can monitor the point cloud not only as it's being generated in real time, but also at the quality it's being scanned. That makes a world of difference to a project. And of course, there's a big advantage in the fact that you can just walk at your own pace and everything is scanned automatically. The GUI shows you exactly where you've been, what you've scanned and at what quality, and that's a fundamentally different approach to a TLS. You can even open doors and move things around while scanning with NavVis VLX. Besides that, there are a lot of additional post-processing features that make it smoother for SLAM devices to deliver exceptional results. For example, two core elements of our user-friendly approach are the way our devices

▲ *NavVis founders (from left to right) Robert Huitl, Sebastian Hilsenbeck, Felix Reinshagen and Georg Schroth with the NavVis M6 mobile scanning system.*

can read SLAM anchors or combine different scans in post-processing (NavVis scans and non-NavVis scans).

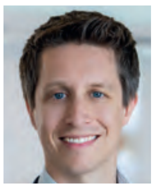
This appears to be the decade of digitalization in the construction industry. How much knowledge of geospatial technology do construction engineers have?

Knowledge is increasing. There was always some awareness about geospatial technology in construction, but it was very often isolated rather than being integrated with the building workflow and tied into a larger digital picture. Of course, geospatial technology requires a broad field of knowledge, and construction engineers already have to take many other things into consideration. It's asking a lot for them to become experts in this technology as well. But I think the construction industry seems to be embracing digitization a lot more. It has been slow in comparison to other industries, making only minimal productivity gains in the past few decades. I believe that scanning will be one of the absolute core technologies which ensures that the construction process becomes more digitized, but that's only a means to an end so it becomes more productive and efficient. Geospatial technology will enable engineers to track their progress in much greater detail and with more precision than ever before. But for that to work, the hardware and software must be a lot easier to use because people on construction sites already have their own areas of expertise; they shouldn't be required to be fully fledged experts in geospatial technologies at the same time. It needs to be tied very closely into the whole process. There's still a lot to do in terms of simplicity, affordability and integration with the typical work of these specialists.

Do you foresee any further trends/developments that will transform the mapping profession?

Plenty! For one thing, I'm confident there will be further developments in automatically generated assets from reality capture. Current examples of automated byproducts are full-colour floorplans and panoramic images. And in addition to mapping professionals, people in adjacent industries like automotive will become increasingly reliant on these assets, completing simple tasks like floor-space optimization without the need to be physically on site. Another next trend is where the scan becomes the model. Sophisticated 3D scanning devices can produce point clouds and images which are so realistic and so easy to implement that they eliminate the need for modelling altogether. This new era of mobile scanning is already embraced by factory planners, who are testing new layouts by taking virtual measurements and moving around cropped sections of the point cloud without having to model anything. Plus, daily scans will ensure that digital buildings are never out of alignment with their physical counterparts. Finally, there is artificial intelligence and computer vision. Today, we're generating spatial data exclusively for the benefit of humans. But, as with autonomous driving, there'll also be a need for spatial intelligence for use by autonomous machines working indoors. As people and robots perform their tasks side by side within complex environments dedicated to manufacturing, logistics and warehousing, accurate laser scan data will be essential for their collective safety and efficiency on the shop floor. ◀

ABOUT FELIX REINSHAGEN



Felix Reinshagen is co-founder and CEO of NavVis, a company specializing in indoor mobile mapping. He has a PhD in information system research and is an active speaker and writer on digitalization, AI, 3D mapping and location-based services.

FEATURES AND PRODUCTIVITY

Multibeam Lidar for Mobile Mapping Systems

In mobile mapping, geospatial data is acquired by one or more cameras and/or one or more Lidar sensors mounted on a vehicle that moves over land, through water or through the air. The distribution of Lidar beams over the scene may be realized by a spinning mirror or by a solid-state device. Multiple beams may be emitted simultaneously, and single or multiple returns may be captured. This article discusses the features and productivity of various multibeam Lidar sensors suited for mobile mapping.

In the case of the selected Lidar sensors, the mechanisms for distributing emitted beams over the scene are based on either a spinning mirror or on solid-state technology. The mirrors may spin in an oscillating or rotating way. These spinning devices have moving mechanical parts which may introduce disturbances and malfunctioning, and thus affect the quality of the measured point cloud. Furthermore, calibration is continuously required, leading to higher surveying costs. Solid-state Lidar sensors have no mechanical parts, but the downside is a limited field of view (FoV) meaning that three, four or even more sensors are necessary to obtain full 360° coverage.

When considering the features of Lidar sensors, operational aspects of the instrument and its measurement characteristics are important for mobile mapping. The main factors influencing the operational aspects are size, weight, power consumption and price. Measurement characteristics include maximum range, range accuracy, FoV and point density – all of which should be high. Point density mainly depends on beam divergence, beam output rate and angular resolution. These measurement characteristics are discussed in more detail below.

▲ *Figure 1: Selected Velodyne Lidar devices.*

MEASUREMENT CHARACTERISTICS

Maximum range: Manufacturers specify the maximum range at either 80% or 10% target reflectivity. For cars and other shiny objects, the reflectivity is about 80% resulting in longer maximum ranges. For pavements and other matt objects, the reflectivity is about 10% resulting in shorter maximum ranges. Given that most of the real-life targets have a low reflectivity rate, a longer Lidar scanning range is preferred. A long maximum range means better coverage, which is beneficial for mobile mapping applications.

Range accuracy usually varies from 2cm to 20cm with respect to the measured range. The higher the range accuracy, the higher the quality of the point cloud representation of road surfaces, road furniture, buildings, trees and other objects of interest will be. After emission, the laser beam diverges and propagates as a cone, resulting in an elliptical footprint when the beam hits a surface. Capturing small objects at longer distances from the vehicle requires small footprints.

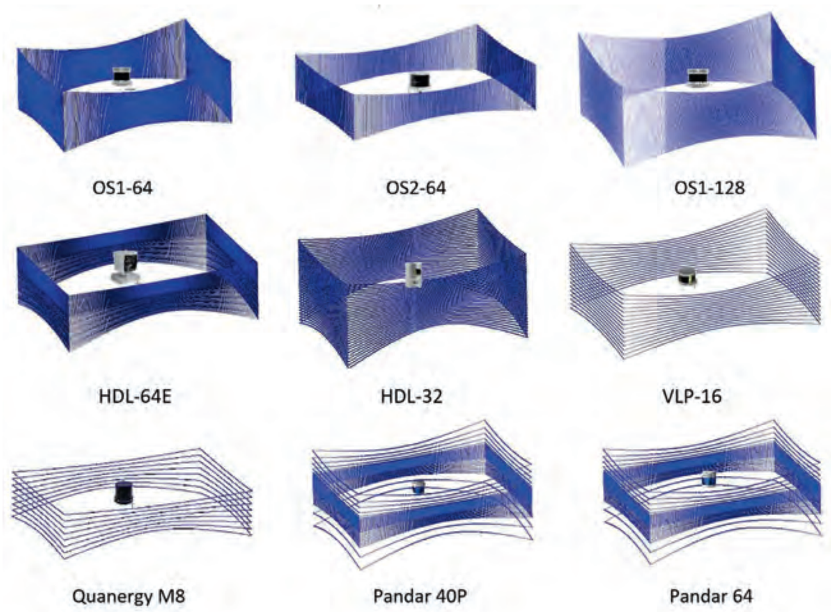
Point density is largely determined by the beam output rate, which is usually specified as points per second (pts/sec) emitted by the Lidar system. If the applications require high point densities, then the beam output rate is crucial. The smaller the angular resolution, which is usually specified for both vertical and horizontal directions, the denser the point cloud and thus the more detail is present. Usually, Lidar sensors capture the first and the strongest returns. These multi-return sensors result in denser point clouds and better object representations.

FoV: Most spinning Lidar sensors have horizontal field of view (HFoV) coverage of 360^{0}. Solid-state systems require three or more aligned sensors to obtain full 360^{0} coverage. On the other hand, the larger the vertical field of view (VFoV), the better the scene is covered.

The features of Lidar sensors discussed above largely determine the survey productivity of a mobile mapping system (MMS). A selection of Lidar systems that are potentially suited for mobile mapping (see Figure 1) have been categorized – based on the specifications given by the manufacturers – into four groups: very-high productivity, high productivity, adequate productivity and others. The specifications of the selected systems are listed in Table 1.

VERY-HIGH PRODUCTIVITY (128 BEAMS)

Three of the selected Lidar sensors have been placed in the top segment of very-high productivity. The main factor influencing productivity is the number of laser beams emitted simultaneously; currently, the maximum number of beams is 128.
With a total output rate of 2.6 million pts/sec for all 128 beams together, the Ouster OS1-128 has the highest output rate of all selected systems. Its price and VFoV of 45˚ give it the edge over the other types. The other very-high productivity Ouster Lidars OS0-128 and OS2-128 are less suitable for the mobile mapping applications because of either shorter scanning ranges or narrower VFoV. With a total output rate of 2.4 million pts/sec for all the 128 beams together, the Velodyne Alpha Prime scores as one of the best spinning devices. Compared to other 128-beam sensors, this system has a wide VFoV, a high number of returns and a long maximum range. With respect to size and weight, the Alpha Prime is one of the largest and heaviest systems. The solid-state Luminar has the longest maximum range and an output rate of over half a million pts/sec. Since three devices are needed to achieve a 360° VFoV, the total output rate is 1.5 million pts/sec. Weighing in at 3.9kg, the system is relatively heavy.



▲ *Figure 2: Scan patterns of different Lidar sensors.*

HIGH PRODUCTIVITY (64 BEAMS)

Four Lidar sensors have been categorized in this segment. Their productivity is lower because the number of laser beams emitted simultaneously is 64, which is half the number in the top segment. The spinning Ouster OS1-64 has an output rate of 1.3 million pts/sec and a maximum range of 120m. The beams are distributed symmetrically around the horizontal plane and the VFoV is good. As a result, this system has many beneficial properties – especially when two Lidar sensors are mounted on the vehicle.

The Ouster OS2-64 also has an output rate of 1.3 million pts/sec and its maximum range is 240m. The narrow VFoV and its larger size make it less suited for mobile mapping however. Both of these Ouster sensors are reasonably priced. Their beam wavelength of 850nm is less absorbed by water particles in the atmosphere, which means that both systems can operate efficiently under high humidity conditions.

Also in the high-productivity category are the Lidar systems from Chinese manufacturer Hesai. The maximum range of the Hesai Pandar64 is 200m at 10% reflectivity, the output rate is 1,152,000 pts/sec and the VFoV is 40° with a resolution of 0.17°. However, the three Hesai systems listed in Table 1 distribute the beams irregularly (gradient) over the scene; they are mostly concentrated in the horizontal plane. This may affect the coverage and uniformity of point distribution.

▲ *Figure 3: Mobile mapping systems in use by a variety of mapping companies.*

▲ *Figure 4: Low-cost multibeam Lidar types in use by a variety of mapping companies.*

The Velodyne HDL-64E has a comparable output rate and the vertical resolution of 0.4° is reasonable. The disadvantages are its weight, size and price. Figure 2 shows the scanning patterns of different Lidar devices in a closed rectangular space where they are orientated vertically without tilt.

ADEQUATE PRODUCTIVITY (32 BEAMS)

Three Lidar sensors have been categorized in this segment. Their productivity is lower than the very-high and high-productivity segments because the number of laser beams emitted simultaneously is 32.

The Velodyne HDL-32 has a VFoV of 40˚ and a maximum range of 120m. It has a reasonable size, weight and power consumption and is used by mobile mapping companies such as CycloMedia, Topcon, Maverick Teledyne Optech and Viametris vMS3D (Figure 3). The features of the recently released Ouster OS1-32 are comparable to those of the Velodyne HDL32, but with a slightly lower output rate. The symmetrical angles above/below the horizon of the OS1-32 are beneficial for capturing above and below-ground objects. Considering its reasonable price this multibeam Lidar is a popular choice, especially when

Lidar sensor	Type/version	Max. range	Range accuracy	Beam divergence	Output rate pts/sec.	VFoV	Rotation rate	Vertical resolution	Horizontal resolution	Pulse return	Weight	Power consumption
Velodyne	VLP-16	≤ 100m	±3cm	0.18°	≈300,000	≈30°	5-20Hz	2°	0.4°	dual	830g	8W
Velodyne	HDL-32	≤ 100m	±2cm	0.16°	≈700,000	≈41.33°	5-20Hz	1.33°	0.4°	dual	1050g	12W
Velodyne	HDL-64	≤ 120@80%	±2cm	0.11°	≈1 million	≈26.9°	5-20Hz	0.4°	0.35°	dual	15kg	60W
Velodyne	Puck Hi-Res	≤ 100m@80%	±3cm	0.18°	≈300,000	≈20°	5-20Hz	1.33°	0.4°	dual	830g	8W
Velodyne	Alpha Prime	> 220m@10%	±3cm	no info	≈2.4 million	≈40°	5-20Hz	0.11°	0.4°	dual	3.5kg	22W
Ouster	OS0-32	≤ 55m@80%	±1.5-5cm	0.35°	655,360	≈90°	10-20Hz	0.7° – 5.5°	0.35°	single	445g	14-20W
Ouster	OS0-64	≤ 55m@80%	±1.5-5cm	0.35°	≈1.3 million	≈90°	10-20Hz	0.7° – 5.5°	0.35°	single	445g	14-20W
Ouster	OS0-128	≤ 55m@80%	±1.5-5cm	0.35°	≈2.6 million	≈90°	10-20Hz	0.7°	0.35°	single	445g	14-20W
Ouster	OS1-32	≤ 120m@80%	±1.5-5cm	0.18°	655,360	≈45°	10-20Hz	0.35° – 2.8°	0.35°	single	455g	14-20W
Ouster	OS1-64	≤ 120m@80%	±1.5-5cm	0.18°	≈1.3 million	≈45°	10-20Hz	0.35° – 2.8°	0.35°	single	455g	14-20W
Ouster	OS1-128	≤ 120m@80%	±1.5-5cm	0.18°	≈2.6 million	≈45°	10-20Hz	0.35° – 2.8°	0.35°	single	455g	14-20W
Ouster	OS2-32	> 240m@80%	±1.5-5cm	0.09°	655,360	≈22.5°	10-20Hz	0.18° – 0.73°	0.35°	single	930g	14-20W
Ouster	OS2-64	> 240m@80%	±1.5-5cm	0.09°	≈1.3 million	≈22.5°	10-20Hz	0.18° – 0.73°	0.35°	single	930g	14-20W
Ouster	OS2-128	> 240m@80%	±1.5-5cm	0.09°	≈2.6 million	≈22.5°	10-20Hz	0.18° – 0.73°	0.35°	single	930g	14-20W
HESAI	Pandar64	≤ 200m@10%	±2cm	0.177°	≈1,152,000	≈40°	10-20Hz	0.167°	0.4°	dual	1.5kg	22W
HESAI	Pandar40P	≤ 200m@10%	±2cm	0.177°	≈720,000	≈40°	10-20Hz	0.33°	0.4°	dual	1.5kg	18W
HESAI	Pandar40	≤ 200m@10%	±2cm	0.177°	≈720,000	≈23°	10-20Hz	0.33°	0.4°	dual	1.4kg	15W
Quanergy	M8	> 100m@80%	±3cm	no info	≈420,000	≈20°	5-20Hz	3°	0.13°	up to 3	900g	18W
Luminar	H-series	≤ 250m@10%	0.7 -2.5cm	no info	≈540,000@120°HFoV	0-30°	1-32Hz	0.03°	0.14°	up to 3	3.9kg	55W
Sense	Sense 30	≤ 21m@10%	±3.5cm	no info	≈65,000 @80°HFoV	30°	10Hz	0.27°	0.27°	no info	4.5kg	25W
Blickfeld	Cube	≤ 100m@10%	no info	0.4°	≤200,000	30° V*100° H	no info	0.4°	0.4°	no info	light	no info
Blickfeld	Cube Range	≤ 150m@10%	no info	0.18°	≤200,000	10° V*15° H	no info	0.18°	0.18°	no info	light	no info

Spinning
Solid state

▲ *Table 1: Specifications of Lidar sensors as provided by the manufacturers.*

multiple devices are mounted in the MMS. Except for the number of laser beams emitted, the features of the Hesai Pandar40P are similar to the high-productivity Pandar64.

OTHERS

There are several other Lidar sensors which may be particularly suited for indoor and unmanned aerial system (UAS) applications. The Quanergy M8 has a small horizontal angular resolution, captures up to three returns per pulse, has a VFoV of 20^0 and emits eight beams simultaneously.
The Velodyne Puck sensors (VLP-16, Hi-Res, Lite) have output rates of 300,000 pts/sec. Their maximum range, range accuracy, size, weight, power consumption and prices are reasonable, but their geometric/scanning properties are less adequate than the HDL-32.
The features of the Hesai Pandar40 are similar to the Pandar40P but the VFoV of 23^0 is narrow. Mapping companies are using some of these Lidar sensors in their unmanned airborne systems and indoor mapping systems (Figure 4). For example, the Australian company Emesent has mounted the Velodyne VLP-16 on its Hovermap UAS (Figure 4a), and Viametris has mounted the VLP-16 (Figure 4b) on its backpack indoor mapping system.
The C2L nebula-LP MMS (Figure 4c) and the GeoCue UAS (Figure 4d) use Quanergy M8.
The maximum range of the Sense 30 – a solid-state sensor – is 21m, which is an impediment for outdoor applications.
The two Blickfeld solid-state sensors listed have a low output rate. The acquisition of dense point clouds requires thus long survey times.
The newly released ultra-wide-view Lidars from Ouster (namely OS0-32, OS0-64 and OS0-128) have a 90° VFoV which is highly efficient for autonomous driving. However, they are less relevant for mobile mapping applications because of their limited maximum scanning range of 20m at 10% target reflectivity.

CONCLUDING REMARKS

Mobile mapping companies that want to conduct large-scale projects or achieve city-wide coverage may benefit from a single multibeam Lidar with high productivity or from integrating multiple Lidar devices from the very-high or high-productivity categories.
Of course, the available budget will play a key role in the system choice. A wider VFoV combined with a longer scanning range, high output rate of points and better range accuracy will always be of significant importance when selecting the most suitable Lidar device for a mobile mapping system. ◂

Author's note: Lidar technology is rapidly evolving and new types are being released all the time. The information provided in this article was correct at the time of writing.

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WHY UNSUPERVISED SEGMENTATION IS THE KEY TO SUSTAINABLE AUTOMATION

Fundamentals to Clustering 3D Point Cloud Data

Automation in point cloud data processing is central for building efficient decision-making systems and to cut labour costs. The identification of objects of interest in these massive datasets constitutes the base of many applications. While new supervised deep learning architectures show promising results, the amount of available labelled 3D data is often insufficient for a good generalization. This is where unsupervised approaches and data clustering shine.

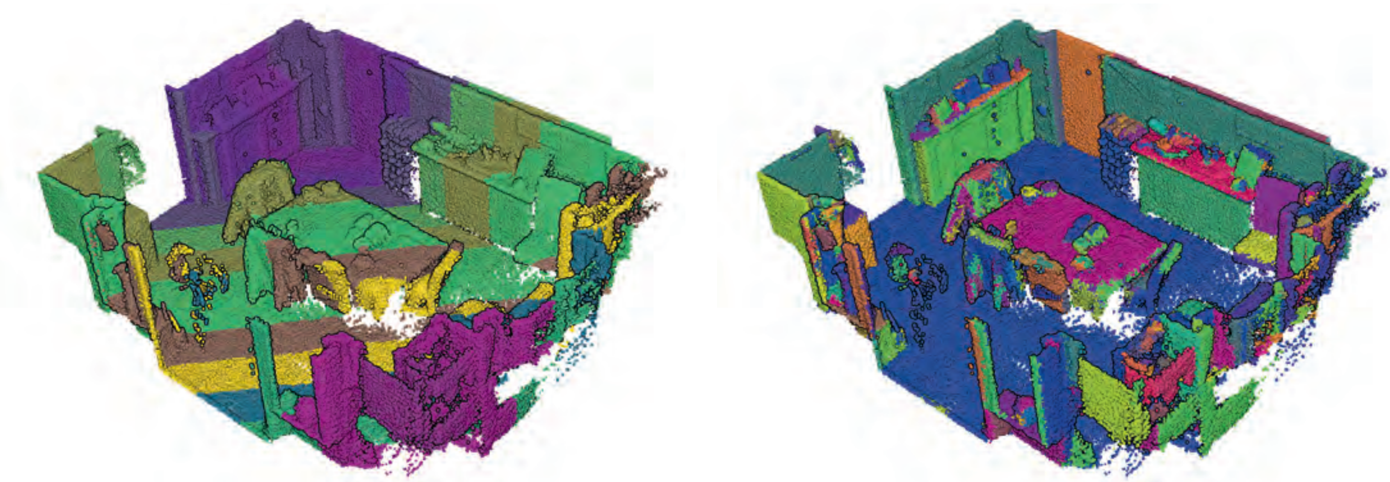
Clustering algorithms allow data to be partitioned into subgroups, or clusters, in an unsupervised manner. Intuitively, these segments group similar observations together. Clustering algorithms are therefore highly dependent on how one defines this notion of similarity, which is often specific to the field of application.

Clustering algorithms are often used for exploratory data analysis. They also constitute the bulk of the processes in artificial intelligence (AI) classification pipelines to create nicely labelled datasets in an unsupervised/self-learning fashion. Within the scope of 3D geodata, clustering algorithms (also defined as unsupervised segmentation) make it possible to obtain a 'segment soup' that becomes the backbone of several processes such as feature extraction, classification or 3D modelling as illustrated below. They most often act in addition to a dimensionality reduction algorithm that allows the different attributes (called dimensions) to be viewed in two or three dimensions. If a 'view' presents sufficient decorrelation, a clustering algorithm can be used to form subgroups of these points: the clusters. This enables the relationships between the points to be visually represented. Alternatively, instead of representing the entire data, only one representative point per cluster can be displayed. Once clusters have been identified, data can also be viewed using only one representative per cluster and discarding the others.

WHY IS DATA CLUSTERING USEFUL?

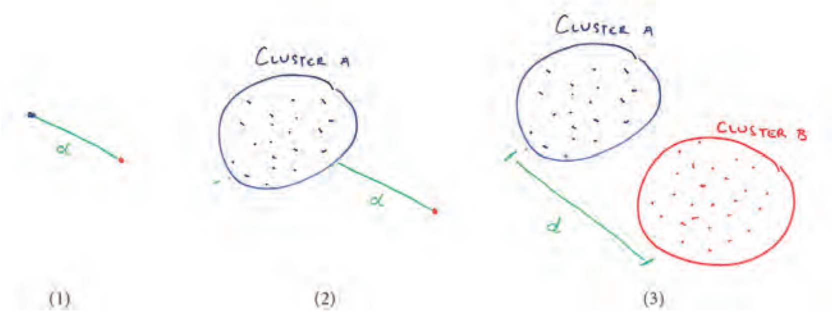
Clustering algorithms are particularly useful in the frequent cases where it is expensive to label data. When annotating a large point cloud, for example, annotating each point by what it represents can be a long and tedious job, to the point that the people doing it can unintentionally introduce errors through inattention or fatigue. It is cheaper and perhaps even more efficient to let a clustering algorithm group similar points together and then only involve a human operator when assigning a label to the cluster.

Thus, clustering algorithms can be used to extend a property of one of the points in the same cluster to all the points in the same cluster (see Figure 2).

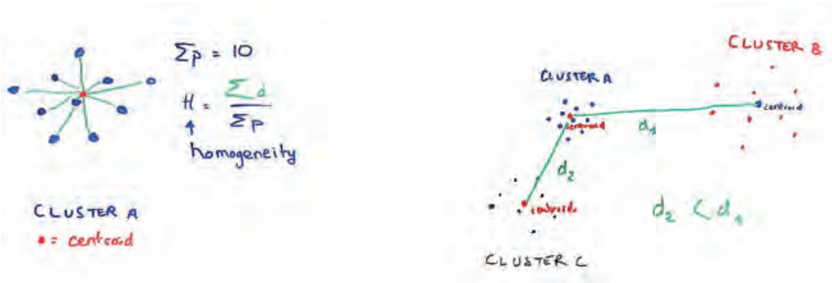


▲ *Figure 1: Different clustering strategies applied to a noisy point cloud of a room (strip vs spatial aggregation). It is evident that spatial proximities seems to be a choice criterion to define a similarity measure.*

▲ *Figure 2: This simple illustration of a chair shows one advantage within semantic segmentation workflows: it is easier to label some representative segments rather than all the individual points.*



▲ *Figure 3: A simple illustration of some distances (1) between two observations, (2) between one observation and a cluster, and (3) between two clusters. (Image courtesy Florent Poux, PhD)*



▲ *Figure 4: A simple illustration of how homogeneity and separation gives intuitive sense to better characterize clusters.*

Several parameters can be tuned to define an interesting partition of the data, later used to derive some of the best-known clustering algorithms (K-means, K-NN, Mean-shift…).

IS THE CLUSTERING REPRESENTATIVE?

In the case of unsupervised algorithms, the purpose of the algorithm is less obvious to define than in the case of supervised algorithms, where there is a clear task to accomplish (e.g. classification or regression). The success of the model is therefore more subjective. The fact that the task is more difficult to define does not prevent a wide range of measures of the performance as detailed below.

DISTANCES AND SIMILARITIES

Clustering means grouping together the closest or most similar points. The concept of clustering relies heavily on the concepts of distance and similarity. These concepts will be very useful to formalize:

- How close two observations are to each other (1).
- How close an observation is to a cluster (2).
- How close two clusters are to each other (3).

The most commonly used examples of distances are the Euclidean distance and the Manhattan distance. The Euclidean distance is the 'ordinary' straight-line distance between two points in Euclidean space. The Manhattan distance is so-called because it corresponds in two dimensions to the distance travelled by a taxi on the streets of Manhattan, which are all either parallel or perpendicular to each other. Thus, a distance can be used to define a similarity: the further apart two points are, the less similar they are, and vice versa. A distance d between x and y can be transformed into a similarity measure. Another common way to define similarity is to use the Pearson correlation which will take into account the shape of the distribution rather than its amplitude, which the Euclidean distance mainly does. The choice of the distance measure is therefore important.

CLUSTER SHAPE

The shape of a cluster is another important element that is initially described as:

- Tightened on themselves - two close points must belong to the same cluster
- Far from each other - two points that are far apart must belong to different clusters.

It is common to search for clusters tightened on themselves. For example, using the Euclidean distance, it is relatively easy to first compute the centroid of a cluster (the barycentre of the points of this cluster). The homogeneity of a cluster can then be defined as the average of the distances of each of the points contained in this cluster to the centroid. In this way, a tightened cluster will have a lower heterogeneity than a cluster of scattered points. Then, to characterize not just one cluster but all clusters in the dataset, it is possible to calculate the average of the homogeneity of each cluster.

Secondly, the clusters must be far from each other. To quantify this, the separation of two clusters is usually defined as the distance between their centroids. Once again, the average of these quantities can be calculated on all the pairs of clusters obtained. To make it easier, these two criteria to be optimized (homogeneity and separation) can be grouped into a single criterion, the Davies-Bouldin index. The idea of this index is to compare intra-cluster distances (homogeneity) – which is desired to be low – to inter-cluster distances (separation), which is desired to be high. For a given cluster, this index is all the weaker as all the clusters are homogeneous and well separated.

Another way to quantify how well a clustering meets the two requirements of homogeneity and separation is to measure the so-called silhouette coefficient to assess whether a point belongs to the 'right' cluster. This calls for a mathematical answer to two questions:

- Is p close to the points of the cluster to which it belongs?
- Is the point far from the other points?

CLUSTER STABILITY

Another important criterion is the stability of the clustering: if the algorithm is run several times on the same data with a different initialization, or on different subsets of the data, or on the same slightly noisy data, does it achieve the same results? This criterion is particularly relevant when choosing the number of clusters: if the number of clusters chosen corresponds to the natural structure of the data, the clustering will be more stable than if it does not.

In the example in Figure 5, an algorithm that tries to determine three clusters will reasonably find the three clusters shown. But if it is asked to determine four clusters, the distribution in those four clusters will be more random and will not necessarily be the same twice. This is one way to determine that three is a better number of clusters than four.

Compatibility with domain-specific knowledge
A clustering algorithm is often also evaluated 'by eye' to see whether the proposed clusters make sense. Do the points grouped in a particular cluster all represent the same object? Do the points in two particular clusters represent different objects? To do this more neatly, it is possible to work on a dataset for which a reasonable partition of the data is known. This partition is then compared with the one returned by the clustering algorithm. For example, when working with a point cloud partitioned by planar shapes, the next step is to evaluate whether the groups formed by the clustering algorithm correspond to those defined a priori.

This seems very much like evaluating a multi-class classification algorithm. But if the issue is whether the same objects belong to the same cluster, it does not matter whether this cluster is the first, the second or the k-th cluster. Therefore, specific performance metrics must be used to evaluate the concordance of two partitions of the dataset. An example of these measures is the Rand index (and its more robust Adjusted Rand Index). The Rand index is the proportion of pairs of points that are grouped in the same way in both partitions – either because, in both cases, the points belong to the same cluster, or because, in both cases, the points belong to different clusters.

CONCLUSION

Unsupervised and self-learning methods are very important for solving automation challenges. Particularly, in the era of deep learning, creating labelled datasets manually is tedious, and ways to alleviate this process are more than welcome. Clustering algorithms provide crucial solutions for this, and are used to partition a dataset into subgroups of similar observations:

- They can be used to better understand the data.
- They can be used to facilitate data visualization.
- They can be used to infer data properties.

To evaluate a clustering algorithm, it is possible to assess:

- The shape of the clusters it produces (dense or well separated), for which the silhouette coefficient is often used.
- The stability of the algorithm.
- The compatibility of the results with domain-specific knowledge, which can be evaluated using enrichment measures.

Figure 5: An example of the 'parameter supervision' for finding clusters and its impact.

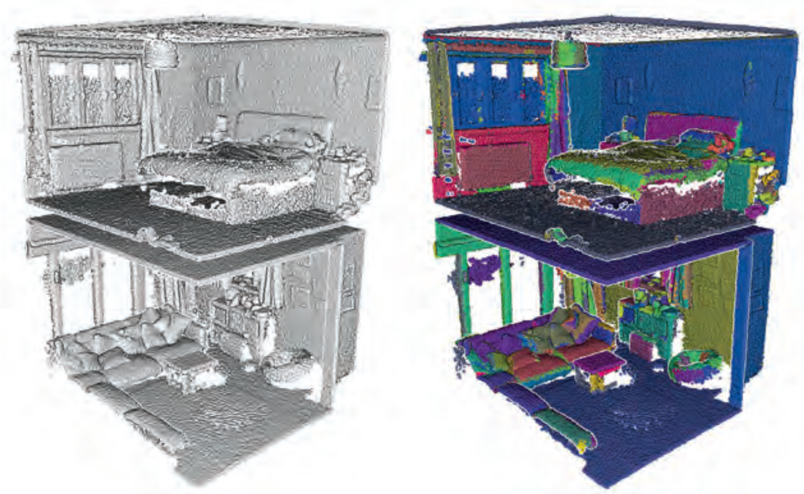


Figure 6: Example of taking a portion of a point cloud and creating a 'planar-labelled' dataset to compare to the clustering results.

FURTHER READING

- Poux, F., Billen, R., 2019. Voxel-based 3D Point Cloud Semantic Segmentation: Unsupervised Geometric and Relationship Featuring vs Deep Learning Methods. *ISPRS Int. J. Geo-Information 8*, 213. doi:10.3390/ijgi8050213

- Poux, F., Neuville, R., Nys, G.-A., Billen, R., 2018. 3D Point Cloud Semantic Modelling: Integrated Framework for Indoor Spaces and Furniture. *Remote Sens.* 10, 1412. doi:10.3390/rs10091412

- Poux, F., Neuville, R., Van Wersch, L., Nys, G.-A., Billen, R., 2017. 3D Point Clouds in Archaeology: Advances in Acquisition, Processing and Knowledge Integration Applied to Quasi-Planar Objects. *Geosciences 7*, 96. doi:10.3390/geosciences7040096

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AN END-TO-END FRAMEWORK USING 3D CNN AND SVM

Full Automation in Mobile Lidar Data Classification

A deep learning architecture called MMCN opens up the possibility for fully automated classification of highly dense 3D point cloud data acquired from a mobile Lidar system. This offers interesting opportunities in applications such as high-density maps, autonomous navigation and highway monitoring.

Classification of highly dense 3D point cloud data acquired from a mobile Lidar system (MLS) is essential in applications like creating high-density maps, autonomous navigation and highway monitoring. MLS data classification algorithms available in the current literature use several parameters or thresholds. The right selection of these parameters is critical for the success of these algorithms under different conditions. This article provides an insight into a deep learning architecture called multi-faceted multi-object convolutional neural network (MMCN). The MMCN, along with the support vector machine (SVM), provides an end-to-end framework for automatic classification of an input 3D point cloud without manual tuning of any parameters, thus providing a possibility for full automation.

ARCHITECTURE

The proposed MMCN algorithm uses multiple facets and multiple objects of an MLS segment (Kumar et al. 2020). An object is a subpart of a segment. Multiple objects of the same segment are generated by creating several subparts automatically. The multiple facets or orientations of each object are created by rotating the object about the x, y and z axes. Different objects and facets thus incorporate information from various portions of the same segment. Further, the input and convolutional layers of the MMCN are separate for each facet, whereas the last convolutional layer of each facet merges at the common fully connected layer. The last fully connected layer is the output layer and uses the softmax function. Therefore, the MMCN is able to account for varied and distinct information about a segment. During the training of the MMCN, the above methodology is applied to manually labelled samples. During classification, segments are created with the help of automatically segmented groups of points (see below for more details); these segments do not need to belong to a single class and can have different levels of noise, background clutter and occlusion as is evident in MLS data. Through training, the algorithm learns local structures and variations within a segment along with noise and clutter. Figure 1 shows the architecture of the MMCN for a segmented group of points.

CLASSIFICATION

The trained MMCN is combined with the SVM to provide an end-to-end framework for completely automatic extraction of multiple

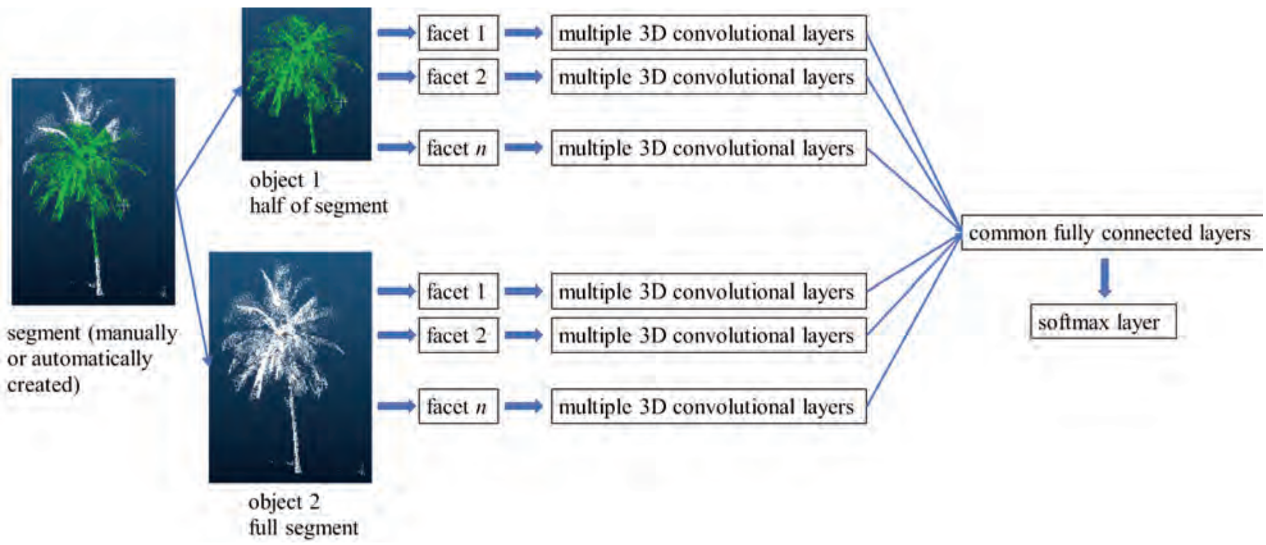
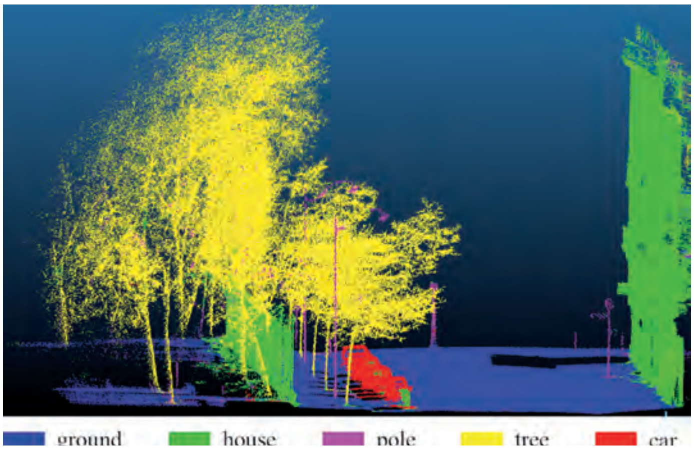
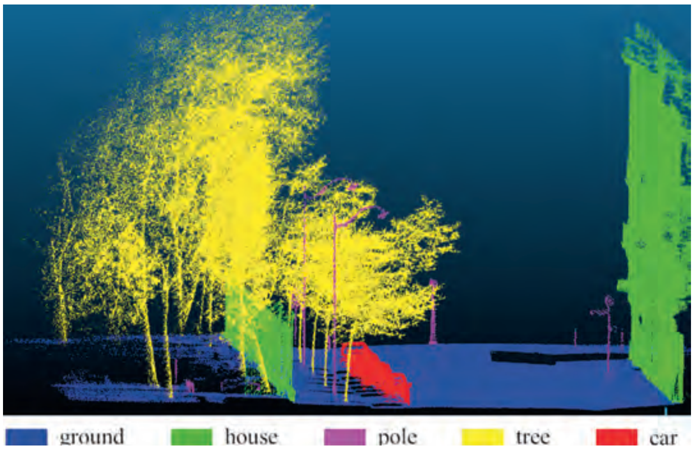


Figure 1: MMCN architecture.



▲ *Figure 2: Classification results.*



▲ *Figure 3: Ground truth.*

segments and classification of MLS point clouds. The developed framework takes an MLS point cloud of any size as input and assigns the class label to each data point. Spherical segments around all the points in the MLS dataset are made for a given radius. These segments are passed through the trained MMCN. For the given input segment, the softmax layer of the MMCN generates a probability vector of belonging to different classes. The same probability vector is assigned to all the points within a segment. It may happen that a point can occur in multiple spherical segments of different radii. In this case, the probability vectors of all such segments are totalled and divided by the number of such segments. This gives the final probability vector of the point for the given radius. Similarly, by varying the radius, multiple sets of probability vectors are calculated for all the points in the MLS dataset. The resulting multiple probability vectors using multiple radii for each point are concatenated and used as a feature vector for training an SVM. The trained SVM then gives the final decision for the classification of the point. Varying the radius around a point forms various shaped segments that incorporate different local neighbourhoods. This provides under-segmentation as well as over-segmentation information to the framework, which is able to learn the variations associated with changing surroundings.

RESULTS

In the developed framework, only the MMCN and SVM need to be trained. Therefore, it is independent of any MLS parameter tuning (multiple radii values can be more or less depending on the available hardware, without requiring any manual tuning). In this framework, only XYZ information about points is required. Further, the network has been developed and trained to learn from segments consisting of noise, occlusion, background clutter and mixed with data points from other classes. The MMCN and SVM have been tested on a Paris-Lille 3D dataset (Roynard et al. 2018) containing more than 142 million data points. The maximum total accuracy and kappa are 96.5% and 93.8%, respectively. More details of the MMCN and SVM can be found in Kumar et al. 2020. Figure 2 and Figure 3 represent the classification results using the MMCN and SVM, and corresponding ground truth, respectively. In the present study, a lower number of convolutional layers, feature maps, neurons and training samples were used due to hardware constraints. That has resulted in some misclassifications.

CONCLUSION

Classification of highly dense 3D MLS point clouds is a challenging task. During practical implementation on the ground with voluminous real-time (or near real-time) data, manual tuning of MLS parameters as is required in traditional classification approaches is not desirable. Instead, a classification algorithm is desired that can work across different terrains and datasets, with few or no changes in the algorithm. The proposed approach can work on any terrain datasets comprising noise, background clutter and occlusion with no tuning. Hence, this provides a wider practical solution for MLS classification. The next step of development is to implement the proposed approach for industry-level data processing. ◀

FURTHER READING

- Kumar, B., Pandey, G., Lohani, B., Misra, S.C., 2020. A framework for automatic classification of mobile Lidar data using multiple regions and 3D CNN architecture. *International Journal of Remote Sensing*. doi: 10.1080/01431161.2020.1734252.

- Roynard, X., Deschaud, J.E., Goulette, F., 2018. Paris-Lille-3D: a large and high-quality ground truth urban point cloud dataset for automatic segmentation and classification. arXiv:1712.00032. Available online: https://arxiv.org/abs/1712.00032 (accessed 9 January 2020).

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The Future of Lidar is Critical to the Future of Our World

What will be the future of Lidar? To quote Abraham Lincoln, "The most reliable way to predict the future is to create it". So what is currently being created in the geospatial market? Lidar technology is developing rapidly, as illustrated by the number of start-up companies to serve the autonomous market which feature traditional mechanical scanning devices, tiny-chip solid-state Lidar units and the emerging FMCW Lidar. The fact that Apple has announced an iPad with Lidar indicates this technology's arrival in the public domain; whereas it was a challenge to even explain our industry a few decades ago, now many consumers are familiar with the term 'Lidar'! Moreover, the availability of the technology on a consumer device could be an enabling medium for building information modelling (BIM) and digital twin efforts in the construction world. But discussions surrounding the future of Lidar have many tangents, and technology is just one of them. This article therefore focuses on Lidar based around a number of relevant themes: Lidar technology, open data and artificial intelligence/machine learning (AI/ML).

LIDAR TECHNOLOGY

Over the last few decades, the growth and development of photonics and Lidar has been dramatic. We have experienced tremendous improvements in our ability to acquire data. The size, performance and productivity of systems has been transformative for the surveying and mapping professions. The way work is performed and the expectations of the end users are constantly changing. The dramatic improvements in the technology have led to higher pulse repetition rates (PRRs) and miniaturization. This will continue until we reach the limits of Moore's Law. The term Lidar refers to a system of various components. This complex system has strengths and limitations, as do the laws of physics. As we reach limitations in one area of these systems, we find advancements in related areas. An example of this is the role 5G will play in improving pose estimation in urban centres. Another example occurs with resolving range ambiguities, which becomes increasingly difficult for single-channel instruments. This impacts system design to accommodate multiple-channel instruments. For instance, each channel is operating at a PRR of today's standard, but with individual looking directions. As a result, we will see more specialized laser scanners for specific tasks, like corridor mapping and power line monitoring, featuring unique scan patterns for minimizing shadowing effects.

The role of miniaturization within electronics is evident with the class of smaller Lidar systems found on unmanned aerial vehicles (UAVs or 'drones'). The marketplace is seeing optimized sensors for corridor mapping borne by vertical takeoff and landing (VTOL) platforms. These new systems are lightweight and their orientation results in reduced object shading. They feature high measurement accuracy and high measurement speed, with distinct multi-target capability.

OPEN DATA

The impact, value and importance of open geospatial data are now regularly seen. The geospatial market has matured in the past decades to the point that it has become critical to how we view ourselves and manage our world. The dashboards monitoring the spread of the COVID-19 pandemic around the globe are an excellent example. Free data from satellite systems showed impacts of the virus spread, regardless of the veracity of the reporting country's statistics, such as by demonstrating the greening of the planet during the economic shutdown.

In the Lidar field, we have examples of country mapping where the result is open to all potential users free of charge and without a licence. This has spawned use in remarkable areas. Many cities, counties and states have used this data to improve the management of their districts. Country mapping efforts are seen all over the globe but the EuroGeographics council is a stellar example of this accelerating trend: countries such as the Republic of Ireland and the Netherlands have established country mapping efforts, and Switzerland has gone 3D in its topographic maps. The NOAA Shoreline Data Explorer to track and monitor storms and sea rise is another example of open data at the service of the population. This example of bathymetric Lidar data is extraordinarily critical for saving lives and property. The impact of smaller UAV-borne bathymetric systems will highlight the ability of local districts to monitor critical wetlands and calculate water loads in rivers and streams to protect us from recurring flooding.

In the USA, the USGS's example of open data is the 3DEP programme. It is used in many of the traditional areas such as transportation and water management. However, the massive amount of geospatial data is free to all and it has been downloaded by many in Silicon Valley to enable them to check their maps and correct their products. This is a big geospatial data utility that is being utilized to assist consumers and companies with correct data.

ARTIFICIAL INTELLIGENCE/MACHINE LEARNING

Lower-level tasks from machine learning such as high-speed classification of point clouds are some of the low-hanging fruit that will facilitate increased productivity. The next level up will bring about the promise of data mining for more accurate forecasting, assessment of impact of changes and the efficient use and allocation of resources. Over the decades, there has been increasing demand for highly accurate, high-definition and increased-density point cloud data with equidistant point patterns. This is what people call 'high fidelity'. This provides the world with the visualization necessary to manage the ecological impact of populating the planet. Thus, we see the importance of geospatial analytics to the management of our world. It has been estimated that we utilize only perhaps 20% of a typical point cloud. Through the growth of AI/ML, we will eventually be able to utilize all the information that the digital signal processing regime of Lidar provides.

The promise of Lidar is in the accuracy and completeness of the information and the integration of the relevant additional sensor data to provide the high-fidelity visualization that is needed. An example is corridor mapping. Corridors are critical elements to our world. Minor geotechnical hazards can create havoc if not caught in time. The need to be able to 'see' physical assets clearly and correctly is paramount. High-fidelity Lidar systems with appropriate sensor integration will become the standard for providing the visualization needed by AI/ML to routinely find issues and incursions and to avoid disasters.

AI/ML, open data and the Lidar technology itself are just some of the critical factors involved in the future of Lidar for the geospatial industry. We may not be able to predict the future but, in view of all the work being done in the industry, we can see that we are on the right path. ◀

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Hi-Target
Hi-Target
Fixed
THIS IS WHY
we go home earlier
iRTK 4
A SIMPLE BUT NOT SIMPLISTIC
GNSS SYSTEM
IMU
Smart Base
Multi-Protocol
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INNOVATING HOW LAND DATA IS COLLECTED AND MANAGED

A GIS-based App Transforms Land Administration

When I started my career as a surveyor, data collection involved hauling loads of heavy tools like total stations, tripods and range poles. Data had to be manually recorded into weatherproof field books using a number-four lead mechanical pencil. Then came the advent of the Global Positioning System (GPS), experimental satellites, receivers powered by car batteries, and PhDs to help us process that data. More recent advances in the field have been exponential. Today's geographic information system (GIS) technology enables surveyors to leapfrog processes for surveying and mapping land parcels.

In business, it has been said that any technology used for automation and applied to an efficient operation will magnify efficiency. The corollary is that automation applied to an inefficient operation will magnify that inefficiency. Surveyors have been improving our operations for decades with tools like electronic data collectors and robotic total stations. These innovations reduced the number of surveyors we needed in the field, but they didn't necessarily simplify our operations. In 2014, the International Federation of Surveyors (FIG) produced the Fit-for-Purpose (FFP) Report. It went a long way towards helping the land administration community view our trade differently, and it led us to reengineer our thinking of how to document and secure land tenure. But the report fell short of delivering any truly new solutions. Traditional land administration tools and workflows were too costly, difficult to build at capacity, unsustainable, and impossible to scale for FFP.

A SINGLE APP

Henry Ford once said about the automobile, "If I had asked people what they wanted, they would have said 'faster horses'". The same holds true for expectations of land administration: 'How can I draft this map faster?' or 'Can you make a total station that cuts my time down in the field?'. Many of the advances that surveyors see today – CAD, robotic total stations and data collectors – are just automating old workflows. But what if we wanted to put all the FFP land administration thinking into a single app? How would we do that? We would need basemaps, data, open standards, modern security, high-accuracy GPS and the ability to work offline as well as configure to local requirements. The Collector for ArcGIS app achieved all of this while being easy to use and scalable for major projects. It was put to the test following a peace treaty in Colombia after the 52-year civil war with the Revolutionary Armed Forces of Colombia (FARC). An ambitious project was undertaken: to restore land rights to the people who lost them during the war.

RESTORING LAND RIGHTS

By the time the Colombian government and the FARC finally brokered a peace agreement in 2016, the half-century civil war had claimed 260,000 lives. Land reform was always at the heart of the conflict. In Colombia, as in many countries, land ownership is concentrated among an elite group. Just 14% of all landowners control 80% of the land, a strong indicator of inequality. During the war, some rural areas were effectively cut off from the rest of the country, as government troops, paramilitary groups and FARC fought over territory. So many people were driven from their land over the years that today Colombia has the world's largest displaced population (nearly eight million). Even for rural Colombians who have remained on their land, property rights are highly conditional in the postconflict era. People who possess small plots of land have no official recognition of their ownership or even the exact dimensions of their plots. In a joint effort with various Colombian governmental institutions, universities and companies, Kadaster International – known for its innovative thinking and contributions to the global land administration community – took on the challenge of speeding up land inventory in postconflict rural areas.

▲ *Young people quickly learn to use the smartphone app that is central to Colombia's fit-for-purpose approach to mapping parcels. (Image courtesy: Kadaster International)*

AN EVOLVING SOLUTION

The team from Kadaster needed a solution that was fast, affordable, participatory, transparent, robust, inclusive, secure, standards based, configurable and accurate. They didn't want to develop and maintain custom software. They looked into Collector, a mobile data collection app that worked seamlessly with a GIS. It enabled efficient data collection, eliminated the need for paper, and was part of the secure GIS environment Kadaster was already using. Developed by engaging with real fieldworkers, the app is almost a living organism, responding to ongoing user requirements and problems. For example, Javier Morales of the University of Twente's Faculty of Geo-Information Science and Earth Observation (ITC) worked with Kadaster International and Esri Colombia to provide direct feedback to the Collector development team, which was critical to success in Colombia. Leveraging the Land Administration Domain Model (LADM), Morales developed new field-data collection techniques in a dynamic environment and methodologies to clearly communicate with landowners about how their boundaries were mapped. This input resulted in additional capabilities built into the app that hundreds of thousands of users now globally have the advantage of using. The project, called Land In Peace, also enlisted the help of local youths and farmers to take field measurements, which built trust as well as saving costs.

IN COLOMBIA EASY-TO-USE GIS TECHNOLOGY IS ALREADY HELPING TO IMPROVE THE LIVES OF MILLIONS

EASY TO IMPLEMENT AND USE

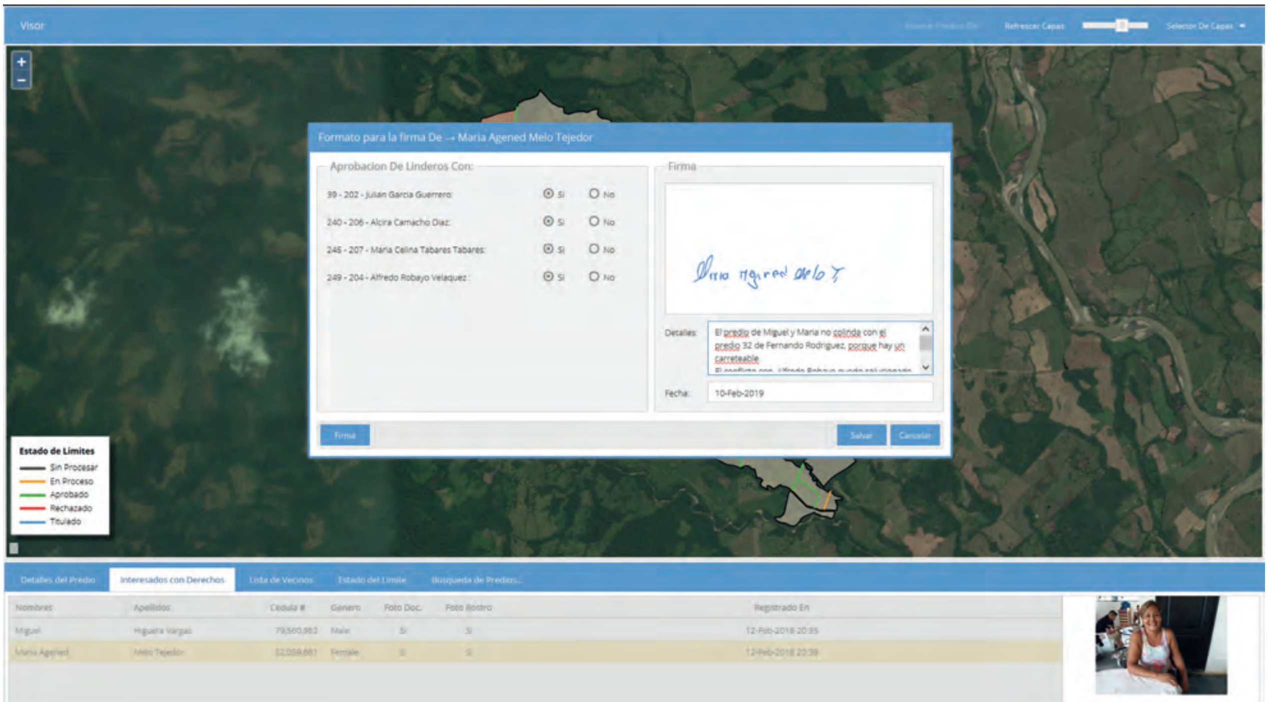
The Collector app is configured and responds to data and services it is connected to, so its use in other land administration systems requires no development. "We now have an application that can be configured to seamlessly address the requirements of land administrators, surveyors and landowners, enabling the fast and reliable execution of all those societal processes that depend on up-to-date land inventories," said Morales. "What is also really great about the Collector app is that it builds up citizens' trust on the procedures, organizations and technology being used to address their needs."

Collector is the interface to the entire geospatial infrastructure needed to collect, manage, analyse and visualize land information. The Collector app connects to massive global datasets including basemaps and imagery, hosted services like geocoding and routing, and analytics for understanding data. Moreover, it is accessible anywhere, by anyone, from any device.

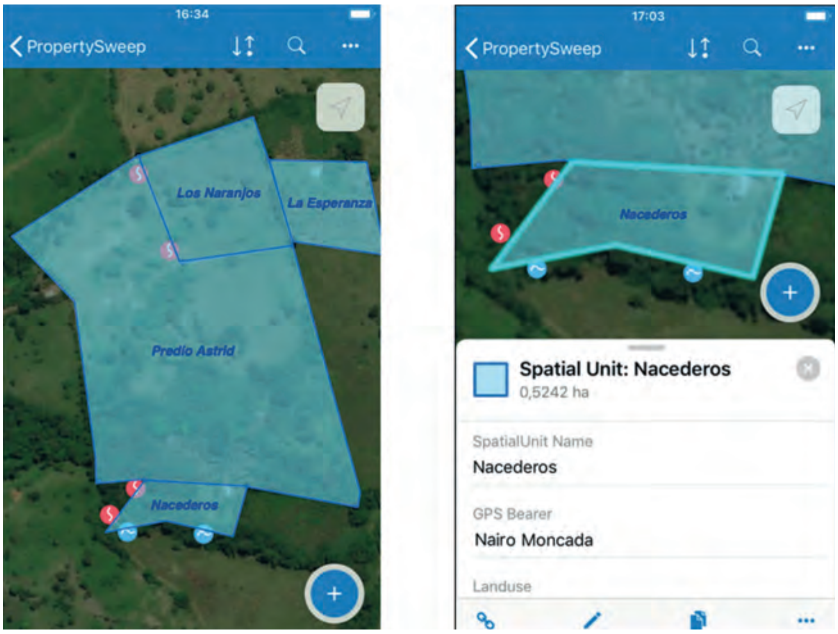
OUT-OF-THE-BOX GIS

Because it is built on open standards and leverages the LADM, the Collector app allows surveyors to use their data in an industry standard and to use the technology out of the box. Surveyors also have access to modern security protocols, as well as the ability to leverage new developments and advancements in iOS and Android technology as they become available. Collector functions offline, so it enables users to conserve data and work in challenging environments that can be remote and disconnected. "The application is designed so that everyone can use it – young people, grown-ups and the elderly," said Yorman Romero Muñoz, one of the local grassroots surveyors involved in the Land In Peace project. "Especially young people, because we love these new technologies so much."

As the work of surveyors and land administration professionals continues to evolve, an easy-to-use and intuitive app is digitally transforming our processes. In fact, in Colombia, this technological advancement is already helping to improve the lives of millions. ◀



▲ *The borders between neighbours (shown in green, black and red) as well as the digital signature that relates the person to the land.*



▲ *The Esri Collector app.*

ABOUT THE AUTHOR

Brent Jones oversees Esri's worldwide strategic planning, business development and marketing activities for land records, cadastral, surveying and land administration. As a recognized innovator, Jones specializes in modernizing existing land administration systems and designing new GIS-based cadastral management systems for small and large governments globally. He is a member of the URISA board of directors, past president of the Geospatial Information and Technology Association, and a current member of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), sitting on the Expert Group on Land Administration and Management.

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FAST SITE VISITS AND ACCURATE 3D MAPPING

Kinematic Laser Scanning for Urban Planning and Infrastructure

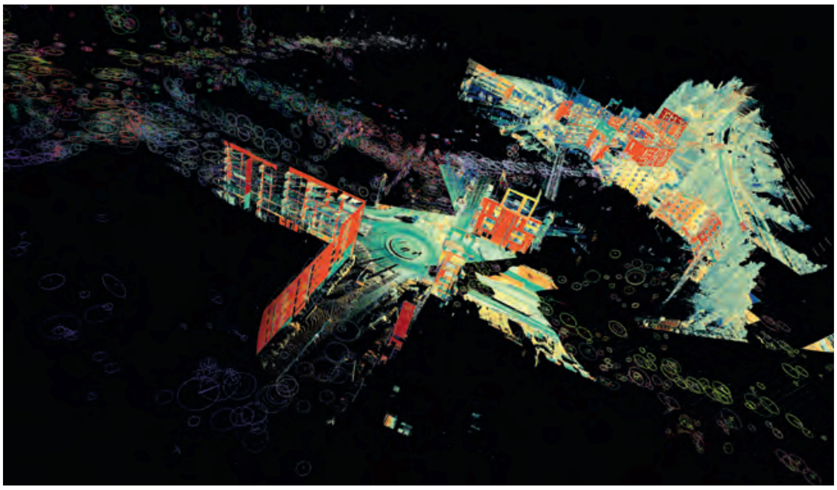
Urbanization and the development of megacities poses critical challenges for sustainable but efficient land use globally. Power lines, pipelines for water, district heating, gas and oil, and other technological systems are critical yet often hidden assets facilitating today's lifestyles. Meanwhile, there is an ever-important need to preserve natural environments and recreational spaces in the world's cities, despite the pressure to spread more concrete and asphalt to accommodate the people and businesses flocking to them. This article examines how kinematic laser scanning can support urban planning and infrastructure management.

There is an ever-increasing need to use the limited urban land area more efficiently. That is boosting the development and use of information systems in 3D, e.g. in cadastre, land use planning and utilities management, and of surveying and documenting technologies to allow high-quality 3D and image data to support such needs. To ensure undisturbed functions, it is essential to know the exact location of infrastructure assets to be able to plan and manage the construction of new pipelines, data and power cables and suchlike, to renovate old systems and to maintain and expand urban green spaces. If such data and information systems are accurate and up to date, operations can be performed faster, minimizing or eliminating unnecessary disruptions, and the urban space can be used more efficiently to support the various utilities, traffic and living-related needs.

Multimodal laser scanning data is increasingly used for surveying and mapping thanks to the development and availability of capable sensor technologies. Small but powerful laser scanning and imaging systems provide applications using virtually any platform for operating laser scanning for 3D reconstruction tasks. Airborne systems and kinematic laser scanning units on vehicles, backpacks and handheld mapping systems can all serve as a means to gather complementary data for diverse user needs and specifications. 3D point clouds provide a common starting point for automated modelling workflows and direct visualization and measurement applications, forming the future topographic core data. They are a significant asset for business and administration in improved forestry, infrastructure management and urban planning. They also provide a platform for developing several future applications.

KINEMATIC LASER SCANNING

Developments in laser scanning and point cloud processing could provide significant cost savings via automation of mapping



▲ *Urban point cloud calibration setting measured with a mobile laser scanning system to reconstruct a digital twin of an urban scene. To transform the raw positioning and laser scanning data into an accurate point cloud representation, it is necessary to calibrate the system offsets and rotational boresight misalignments – here using planar features extracted from the scene.*

processed with improved output and quality of data. Kinematic data collection is permitted mainly by two distinctive technologies: GNSS-IMU positioning and simultaneous localization and mapping (SLAM), both of which are means to track the movements of the surveying laser scanning devices during operation. The former provides the data inherently in the global geographic coordinate system, while the latter typically provides local project coordinates for the data. What makes the use of laser scanning in mapping so effective is the capability to direct 3D measurements for the targets in the line of sight of the beam. To yield such information, certain principles of laser ranging have been deployed. The way to gain range measurements is to transmit short but powerful laser pulses at a fast rate towards the target area and collect the backscattering signal. The signal is then processed to detect objects at distinct ranges within the beam illumination area. With the positioning trajectory, data synchronization and system boresight calibration, the data is then processed into a usable 3D data. The prominent end product of such surveys is a point cloud, where each point location is known in 3D in a project or geographical coordinate system. Such data provides instant visualization and measurement capability, but generalized virtual and terrain models are often desired for compressed data volumes and distribution.

ASSESSING URBAN LAND USE

Urban land use management is increasingly critical to ensure sustainable development and to facilitate safe and thriving communities and environments in ever-growing urbanizations and megacities. In principle, the urban space is divided into use for living, business and public functions, traffic, parks, recreational and natural environments and utilities. All of this needs to be managed somehow. Modern laser scanning technologies make it possible to map the complex urban space using various approaches, from the air and the ground. For a general view airborne laser scanning, often supported by aerial imagery, provides a versatile data source for assessing terrain and building-related data at large scale. This allows powerful tools for detecting new buildings and roads and monitoring landfill sites, earthworks, illegal constructions, deforestation and other such low-detail indicators, typically at an accuracy level of 10-50cm.

▲ *Drone-based high-resolution laser scanning data over an urban area gives a detailed overview of the use of the space in 3D and allows updates for the city plan.*

▲ *Drone data from a suburban area can be utilized to assess land use and update city planning and the cadastre. Laser reflectance information in high resolution gives hints of surface materials and helps with separating and identifying objects.*

For more detailed management and especially for planning purposes, a higher accuracy and resolution is desired. For example, a more accurate assessment of the earth fill/removal volume before constructing a road or building could enable the contractors to save costs, and even more so if they could monitor the progress of the excavation/earthworks in near real time to control the excavation and manage the fleet of dumper trucks. It could also allow for adjustment of the design for superficial structures after the fact, if needed.

High-resolution laser scanning data could be acquired from the air using unmanned aerial vehicles (UAVs or ‘drones’). Airborne scanning permits easy access over sites with obstacles such as fences, excavations and construction sites, and enables images to be captured of the roof structure of buildings, power lines and so on. Typically the instruments also provide more precise measurements than those from higher-altitude applications, and data density typically ranges from 50 to hundreds of points per square metre. From such data, different aspects of urban land use could be resolved in high detail: streets, kerbs, ramps, building outlines and heights, urban green spaces and ground cover, playgrounds, bridges and culverts, to name but a few.

The drone data can be complemented or substituted from the ground perspective using mobile laser scanning (MLS) systems. These systems could be operated using wheeled vehicles, and that data typically provides street perspectives of the areas of interest. In certain cases smaller vehicles could be used to access limited urban spaces. Alternatively backpack or handheld instruments could be used to obtain the data that is needed for the task at hand. Such data typically could cover block interiors, recreational areas, playgrounds and parks and provide a high level of detail of the building mass, passages and street layout and utilities.

MONITORING CONSTRUCTION

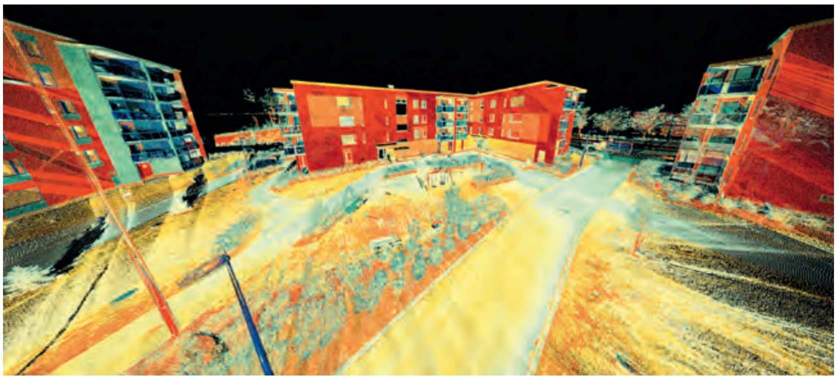
Monitoring construction activity is one of the key areas of interests in city administration. Kinematic laser scanning data allows for a complete understanding of the construction placement, foundation levels related to the surrounding terrain, streets and water runoff drains.

From the land developer and contractor vantage points, laser scanning provides a great tool for documenting the progress of the construction work and placement of the foundations or technical installations prior to proceeding to the next phase in the process for qualification approval and documentation. Accurate data allows dimensional checks and the possibility to adapt the design of prefabricated elements if needed to save costs and delays.

From a safety and accessibility point of view, the accurate 3D data allows planning and managing the use of the space on the site to design areas for lifting, storage and traffic. The data also permits documentation of the site safety installations such as fences and diversion of roads and traffic past the site. Such data can then be distributed to the city management or road administration to report the arrangements for public announcements and traffic control.

DOCUMENTING INFRASTRUCTURE

Public and private infrastructure serves the communities with everyday commodities that are often taken for granted in urban living, such as electric power, water and heating, let alone functional traffic systems with roads and streets and associated assets. To maintain this infrastructure for undisturbed delivery takes effort and cost, both of which could be minimized by exploiting modern asset-management technologies. Up-to-date and accurate 3D asset databases supported by surveying technologies providing accurate 3D data help prevent collateral damage when excavating, and could be used to share asset information between contractors and other parties involved in any particular construction.

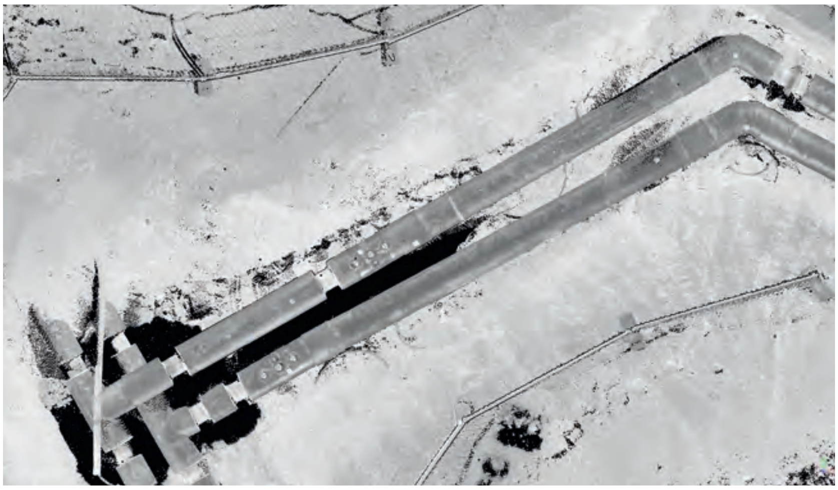


▲ *Recreational space around an apartment block mapped with backpack kinematic laser scanning. Data provides a precise ground perspective of the land use and construction. Dense point cloud data also allows for fast visualizations.*

▲ *Site of a new apartment building. Kinematic 3D data allows not only quick documentation of the construction phase, but also a means to monitor the land use, terrain shaping and drain elevations, and to inspect the building foundation level and placement of the construction versus the permit and city plan.*

▲ *Earthworks and blasting of bedrock on a construction site with newly laid building foundations.*

Overhead cables are a prominent feature present in any urban landscape and also in electric railways. They occupy the low skies of urban areas, hanging across streets and cutting through parks and forests. Kinematic laser scanning is particularly suitable for corridor-type applications, and power lines are well-defined corridor-type objects of interest. Kinematic laser scanning provides ease of deployment and data collection with good precision and level of detail for asset modelling and monitoring. The mapping is not limited to the power line itself, but can also generate accurate information on the terrain and vegetation in close proximity to the line. Beyond the roads, the mobility within the corridor can be achieved by using an all-terrain vehicle or deploying a specific backpack laser scanning system for the mapping task. The main advantages of MLS over airborne laser scanning (ALS) are higher detail from close to the objects of interest, less need for experienced operating personnel, and general operability in challenging weather conditions (e.g. in high winds or rain).



▲ *Installation of an underground pipeline for district heating. With kinematic laser scanning the public works could be documented for future maintenance and renovation planning.*

▲ *Railway installations captured in a backpack-collected 3D Lidar point cloud data for asset documentation and modelling. Accurate locations of rails, supports, portals, wires and isolators, cable wells and balises, among other things, are well visible and identifiable from the precise point cloud.*

Underground installations – such as power cables, water and gas pipes, sewers, drain and district heating pipelines – are usually buried underground to increase the efficiency of the use of space, but often also to improve safety and guarantee undisturbed delivery. However, this poses a risk of damage and disruption when the exact location and depth of the installations is not well documented and new construction needs to be done in the area, or there is a leak in a pipeline, for instance. With kinematic laser scanning such documentation is possible, plus the reach of the laser beam reduces the need to climb into the excavation area, which increases crew safety and speeds up the process. In a single pass, the surveyor can assess the installation, surrounding earthworks and overall geometry of the objects of interest at a high level of detail. Later, back in the office, the current state of the installation, location of technical components and the main pipeline can be transferred into a database for distribution and future use. A similar application is often found in industrial facilities with complex pipeline and power distribution installations.

CONCLUSION

The application of kinematic laser scanning in urban settings provides detailed information for many purposes related

▲ *Longitudinal cross-section of the pipeline shows the weld seam locations and progress of the seam insulation, pipe inclination and depth positioning with respect to the earthfill.*

to the management, development and documentation of human activity and interaction with nature and the terrain. Kinematic data collection using laser scanning, whether GNSS-IMU or SLAM-based, allows fast site visits without disturbing the operations, and captures accurate dimensions of and relationships between objects that are not necessarily available using conventional surveying tools. With kinematic laser scanning data, the actual condition, construction phase and component locations of the installation could be digitalized, or the whole site could be conveniently surveyed and documented in 3D. Mapping and documenting different uses of urban environments, land cover and terrain features and vegetation are prominent applications of kinematic laser scanning in an urban setting. This helps future usage and appropriate planning of the urban space and land use. ◂

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CONSIDERATIONS WHEN CHOOSING APPLICATION DEVELOPMENT PLATFORMS

Emerging Web and Game Engine Tech for 3D Cities

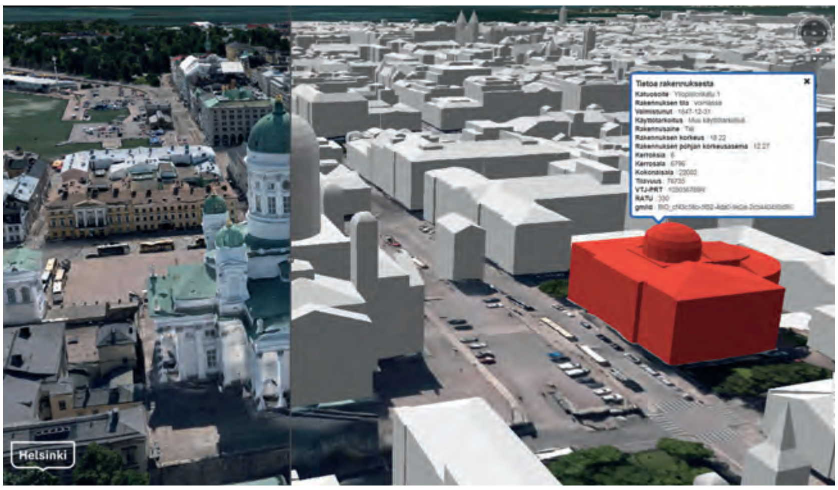
The increasing number of solutions for developing 3D city model applications poses a challenge for developers. This article outlines key considerations that help them to create applications efficiently while utilizing the potential benefits of the 3D data.

3D city modelling has become an established activity in major cities. As a part of this development, city models are increasingly developed to support numerous applications that involve large user groups, such as collaborative urban planning, pedestrian navigation, event planning and the discovery of services and businesses in cities.

The 3D city models themselves, produced by cities, public organizations and private companies, are increasingly widely available, in some cases even as open data (Figure 1). Furthermore, thanks to the huge amount of open software, tutorials and other educational material that is available from online communities, learning how to utilize geospatial data has become easier than ever before.

Applications that utilize 3D city models can be developed with an increasing number of software solutions, ranging from simple tools to complex systems. This alone poses a challenge for developers when choosing the right solutions. Creating applications efficiently while utilizing the potential benefits of the 3D data remains the key challenge in 3D city modelling.

For developing applications, two categories of platforms have been especially topical in recent years: browser-based 3D environments and 3D game engines. While both of these platforms offer 3D visualization capabilities, the game engines have been at the forefront of the virtual reality (VR) and augmented reality (AR) boom. At the same time, browser-based 3D has made it possible to create applications that can be easily distributed to large user groups and operated without separate software installations.



▲ *Figure 1: Helsinki's 3D city models are available as open data assets – the reality mesh model (left) and the semantic city information model (right).*

BROWSER-BASED PLATFORMS

The development of browser-based 3D rendering has enabled the transition of interactive 3D applications from desktop systems to browsers. Browser-based solutions often rely on WebGL technology and are limited by the performance constraints inherited from web browsers and the internet. At the same time, however, they are inherently close to easy sharing, online participation and the visualization of live data streams (e.g. from Internet of Things systems).

For geospatial online 3D systems, numerous use cases exist globally, applying 3D virtual globes as either the generic publishing platforms of 3D city models or for more dedicated use cases such as energy (e.g. the Helsinki Energy and Climate Atlas, see Figure 2).

In 3D GIS and virtual globes, browser-based systems have matured into entire software ecosystems that have come to include standardized data formats such as 3D tiles. The most commonly applied open-source components, such as CesiumJS, GeoServer

▲ *Figure 2: The Helsinki Energy and Climate Atlas contains energy-related building information in a visual and informative form and allows the user to explore Helsinki in a browser while retrieving information about buildings.*

or 3DCityDB, have become starting points for several commercial products (e.g. virtualcityMAP) or open-source frameworks (e.g. TerriaJS).

3D GAME ENGINE PLATFORMS

A second significant development track has been the emergence of game engines as platforms for professional applications (e.g. visualizations, virtual experiences, simulations and gamified training) involving GIS data and building models. Game engines still lack the native support for geographic coordinate systems or map projections, but they excel in the visual quality and performance provided by the real-time 3D rendering that allows for engaging real-time interactions and experiences, VR and AR. Major software vendors have introduced tools that simplify the utilization of urban datasets on game engine platforms.

The most popular game engines have vast developer communities and offer extensive documentation that flattens the learning curve and makes them easier to access. Nowadays the game engine companies have started to invest heavily in expanding the utilization of their platforms outside the traditional fields of digital gaming and entertainment, such as in the automotive and AEC industries. The games industry is also showing a growing interest in utilizing 3D spatial data (e.g. the massive use of globally generated 3D data in the new Microsoft Flight Simulator).

Unity and Unreal Engine have arguably been the most popular game engine platforms for creating interactive visualizations and experiences based on 3D city data. The increasing variety of data conversion tools and plugins makes the game engines an attractive and flexible data integration platform for generating 'digital twin'-style applications. Game engines have been widely used for photorealistic 3D visualizations (see Figure 3 for an example), typically covering culturally significant sites, planned future city areas and construction projects containing participatory elements for citizens.

TECHNICAL FEATURES AND ASPECTS TO CONSIDER

When creating 3D city model applications, the developer should consider the technical features and capabilities of the platform according to the application. These can be related to the support for 3D geoinformation (i.e. geographical coordinate systems and APIs), visualization capabilities (e.g. real-time rendering, support for VR/AR), flexibility of use (e.g. web use, openness, the level of interactivity), data integration and management (e.g. integration of semantics, sensor data or other meaningful data types) and support for 3D data assets (e.g. mesh models, point clouds, CityGML, BIM models, etc.). Some of these properties are explained and briefly discussed below.

SUPPORT FOR GEOSPATIAL INFORMATION

As the application platforms are likely to be utilized with various geospatial datasets, their ability to support these is often quite critical. This may include aspects such as the support for geographic coordinate systems and support for large coordinate spaces that are required for citywide, national or global datasets. In addition to storage formats like GeoTIFF or CityGML, being able to fetch data via interfaces commonly used to exchange GIS data (e.g. WFS and WMS) can be extremely useful and reduce the need for additional data preparation.

VISUALIZATION CAPABILITIES

The level of visualization is essential for communicating the desired information to the users. Contemporary game engines and the WebGL technology used in web browsers both rely heavily on real-time computer graphics. Real-time 3D graphics allow developers to create engaging interactive visualizations and experiences such as, for example, by enabling the user to move freely in the scene with dynamic real-time illumination.

Many of the most advanced visualization techniques are driven by and applied in the video games industry. Modern rendering techniques such as physically based rendering (PBR) can increase the photorealism of the scene even further. Additionally, the support for immersive visualizations via VR and AR can be extremely powerful tools for communicating the city environment using a real-life scale and dimensions. With applicable display devices – such as head-mounted displays (HMDs) or

▲ *Figure 3: A photorealistic and highly detailed 3D model of Helsinki in Unreal Engine.*

mobile devices – VR and AR can be natively applied using game engines or, at least to some degree, on the web (e.g. via the WebXR standard).

FLEXIBILITY OF USE

In the case of an individual 3D application development platform, the flexibility of its use consists of several components:

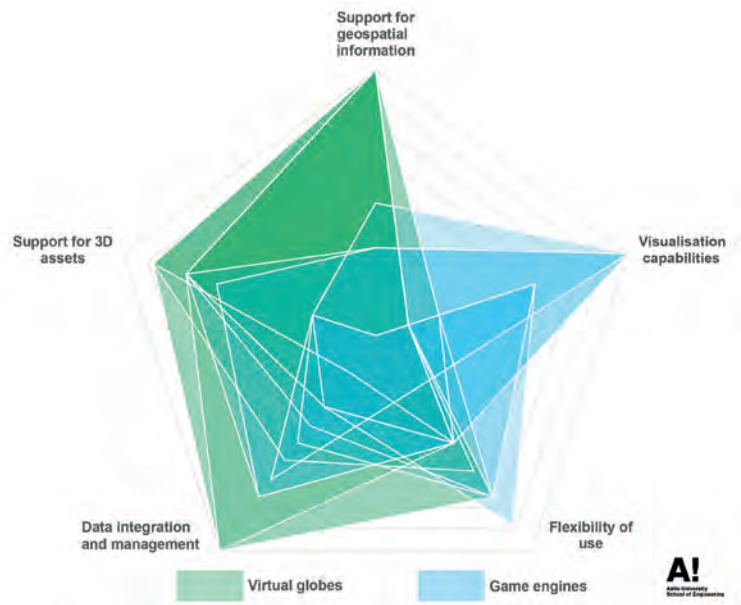
- The ability to deploy the application on a web browser increases its accessibility and removes the need for separate installations and plugins. Needless to say, this is a significant advantage for many of the browser-based platforms.
- 3D city model applications can become powerful tools for communication and information dissemination. Building on this, the ability for multiple users to simultaneously add comments and interact can be extremely useful, especially in participatory use cases. This approach is most pronounced in real-time multiplayer applications and is typically realized in game engines.
- The licensing of the software and its 'openness' also play an important role in the flexibility of use. Both open-data and open-source movements are strongly present in the city modelling scene. This is interesting for application development, as a growing number of platforms for distributing geodata and developing applications are available as open-source platforms. For example, Unreal Engine is free to use and even to monetize under a gross revenue of US$1 million.

DATA INTEGRATION AND MANAGEMENT

Data integration is at the core of a meaningful application and can be seen as a key enabler for urban data analysis and the creation of digital twins. By generating a semantic information model of a city, integrating attribute information (e.g. data related to a building cadastre, city plans, utility networks) or other additional information (e.g. statistics, city services and businesses), the 3D city model can be more than just a visualization of a city environment. Furthermore, an increasing amount of data is being collected using real-time sensors related to traffic, weather and building HVAC systems, for example. 3D city models can act as a platform for integrating and visualizing these data sources.

In addition to containing individual points of dynamic data, cities themselves are dynamic and constantly changing environments. As a result, it can be useful to communicate the changes in the city environment using time series data, for example. This time-dependent data can be historic data, or simulated or planned data describing the future.

In terms of data management, it is possible for 3D city models to include data at various scales and levels of detail. Simply managing the sheer volume of data is a common challenge. It is therefore wise to consider a platform's ability to handle multiple levels of detail and apply optimization methods in storage and loading in order to facilitate big data volumes.



▲ *Figure 4: An overview of the capabilities offered by the available virtual globes and game engines for each technical feature type, illustrated for a set of openly available platforms.*

SUPPORT FOR 3D ASSETS

Needless to say, for building applications that utilize 3D data, the support for various 3D data assets used in the urban modelling context is crucial. The different 3D asset types include dense, coloured point clouds (e.g. LAS, E57), large textured mesh models (e.g. OBJ, FBX, glTF), various semantically enriched city information models (e.g. CityGML, CityJSON) or building information models (e.g. IFC), offering a highly detailed view of an individual building. Furthermore, support for flexible data formats that are suitable for several asset types, such as 3D tiles, is becoming increasingly important.

CONCLUSIONS AND LIKELY FUTURE DEVELOPMENTS

Considering the complex and diverse nature of 3D city modelling, there is no single platform to meet all the requirements related to producing, upkeeping, maintaining and utilizing 3D models of city environments. The virtual globes and game engines currently available tend to highlight slightly different technical aspects (see Figure 4). The application development requires flexible platforms that enable the development of accessible, open, visual and interactive applications that respond to user needs. Achieving this flexibility often calls for solutions that are available as open-source solutions or that are at least free to learn.

One of the most interesting developments in the context of application platforms for 3D

FURTHER READING

- On development of browser-based interactive 3D applications:
Julin, A.; Jaalama, K.; Virtanen, J. P.; Maksimainen, M.; Kurkela, M.; Hyyppä, J.; Hyyppä, H. Automated multi-sensor 3D reconstruction for the web. *ISPRS Int. J. Geo-Inf. 2019*, 8(5), 221. http://dx.doi.org/10.3390/ijgi8050221

- On current platforms for 3D city models:
Julin, A.; Jaalama, K.; Virtanen, J.P.; Pouke, M.; Ylipulli, J.; Vaaja, M.; Hyyppä, J.; Hyyppä, H. Characterizing 3D City Modeling Projects: Towards a Harmonized Interoperable System. *ISPRS Int. Geo-Inf. 2018*, 7, 55. https://doi.org/10.3390/ijgi7020055

- On utilizing 3D geospatial data in virtual reality:
Virtanen, J.-P.; Daniel, S.; Turppa, T.; Lingli Z.; Julin, A.; Hyyppä, H.; Hyyppä, J. Interactive dense point clouds in a game engine. *ISPRS Journal of Photogrammetry and Remote Sensing 2020*, 163(162), 375—389. https://doi.org/10.1016/j.isprsjprs.2020.03.007

city models is the progress of browser-based game engines. This holds the promise of not only bringing game engine-like features to browser-based 3D applications, but also of integrating the visualization capabilities, such as VR, with future online GIS applications. The same process of integration can be observed in the increasing use of game engines for professional applications, even resulting in the integration of game engines and virtual globes. Examples of this are already emerging in the software ecosystem.

Technologies and the software landscape are constantly changing with promising outcomes. Studying and advancing the utilization of the available 3D city data is crucial in order to fully exploit the potential benefits provided by the data. Despite the often-stated challenges in data quality, interoperability, standardization and management on both technical and organizational levels, there is an increasing amount of feasible and openly available data that is waiting to be utilized beyond the scope of cities themselves. ◀

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Cultural Heritage and Virtual Tourism

COVID-19 has transformed our lives and our ability to travel and explore the world like no other event in recent memory. For our cultural heritage institutions, this has drastically altered typical visitation patterns and disrupted the revenue that flows not only directly to these organizations and sites, but also to the surrounding economic ecosystem that is fuelled by tourism. According to estimates by the United Nations World Tourism Organization (UNWTO), international tourist numbers in May 2020 were down 98% from the previous year and very significant effects are likely to be felt throughout this year and next.

This has brought a renewed focus on the importance of digital outreach and virtual visitation to access a remote audience of tourists and visitors who are now no longer physically able to travel to these places. It also presents a new opportunity to build a foundation for reaching a much wider audience than just those that can make the physical journey, and for providing virtual access to previously restricted sites or areas.

DIGITAL CULTURAL TWINS

We are fortunate that reality capture technology has progressed so far. Today, a compelling facsimile or 'digital twin' of these places can be constructed and rendered to provide a compelling backdrop for rich storytelling that aims to transport the virtual visitor to these places. These digital twins can be created using a variety of methods, but two technologies in particular have revolutionized the speed, fidelity and cost with which they can be produced. Consumer drones with high-quality imaging capabilities have made small to medium-scale aerial photogrammetry projects highly accessible. Combined with DSLR-based terrestrial photogrammetry, comprehensive coverage of even large sites and structures is possible in a short period of time. Software solutions for processing these inputs into a homogenous and high-quality textured mesh such as RealityCapture and Pix4D have evolved rapidly in recent years in terms of both ease of use and quality of the final model.

VIRTUAL AND AUGMENTED REALITY

In recent years, the advent of standalone virtual reality (VR) headsets with six degrees of freedom tracking (the ability to track rotation and translation of the headset) has opened up room-scale VR to a whole new audience of users. Affordable devices such as the Oculus Quest (US$399) and HTC VIVE Focus (US$650) are easy to set up and provide an immersive user experience. 360-degree tours (either 360-degree panoramas or 360-degree video) were long the staple for the immersive presentation of real-world places but often disappointed

▲ *The Gateway of India is a remnant of the country's colonial history and also its resilience. Today, it remains one of the most visited sites in Mumbai. In 2019, CyArk documented the structure using aerial and terrestrial photogrammetry combined with Lidar. The 3D data will be used for further preservation of this iconic structure.*

end users with their lack of fidelity and limited ability to explore beyond a linear and predefined path. In recent years, a number of applications have taken advantage of high-detail 3D models to present a more compelling and open-world experience. Masterworks and National Geographic Explore VR are two examples of apps that allow users to explore open environments, providing them with interactive tasks and commentary to learn about the histories of the relevant sites within stunning photo-realistic environments.

Augmented reality (AR) presents another experiential medium for the display and presentation of these digital replicas. Tabletop or markerless AR allows the user to fix a virtual object in a location within a real-world scene (such as on a tabletop) and inspect and explore the object by moving their mobile device. Organizations such as Google Arts and Culture have curated 3D objects from cultural institutions around the world and made them available via the Pocket Gallery allowing for exploration in an AR environment.

The intersection of world events and technology for the recording and presentation of cultural heritage has presented an opportunity to not only reach absent tourists, but also build a future platform for the presentation of sites to a much wider audience. The potential of VR and AR to allow users to virtually experience real-world locations is just beginning to be tapped and will be further fuelled by the availability of high-quality photo-realistic 3D models for users to explore. ◀

ABOUT THE AUTHOR

John Ristevski is the chairman of the board and CEO of the non-profit CyArk. Previously he was the vice president of reality capture and processing at Nokia's mapping company, HERE, where he led the company's initiative to index reality. He joined HERE in 2012 through the acquisition of his company, earthmine, which developed systems to capture and deliver highly accurate street-level imagery and 3D data of cities. John Ristevski is a Fellow of the Royal Institute of Chartered Surveyors and has lectured at Stanford's Civil and Environmental Engineering Department. He has an MSc from the University of California at Berkeley, USA, and degrees from the University of Melbourne, Australia, in both geomatic engineering and law.
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A GENERIC WORKFLOW FOR AUTOMATIC BUILDING DETECTION AND 3D MODELLING

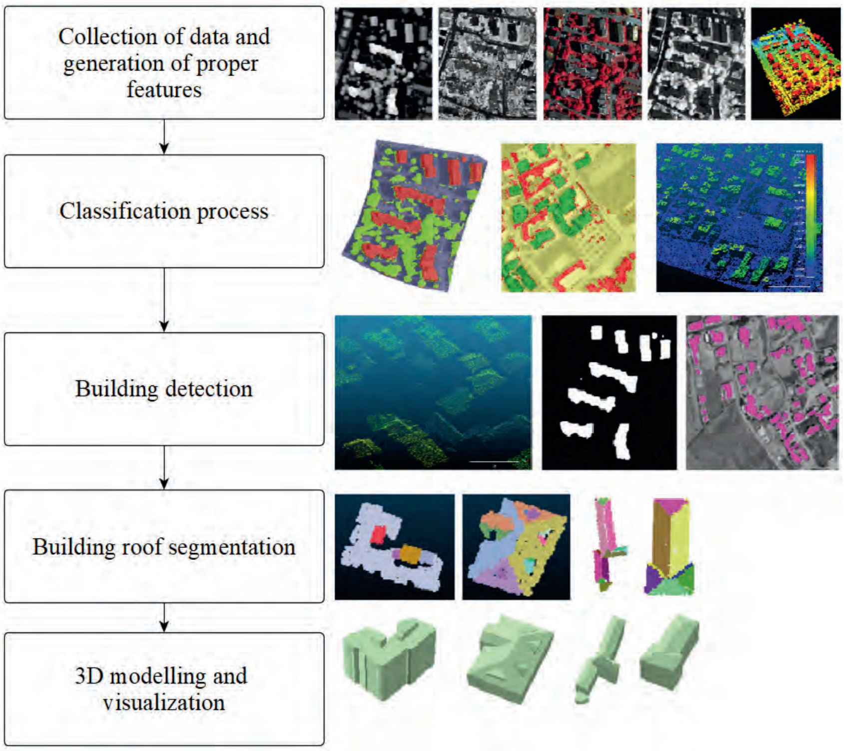
Advanced Urban 3D Modelling and Visualization

The automatic detection, data extraction, 3D modelling and visualization of buildings in urban areas using remote sensing data is an essential task in various applications such as cadastre, urban and rural planning, change detection, mapping, updating geographic information systems, monitoring, housing value and navigation. Even today, this task still remains challenging due to the inherent artefacts (e.g. shadows) in the remote sensing data used, as well as the differences in viewpoints, surrounding environment, complex shape and size of the buildings. This article outlines a generic workflow using modern technologies.

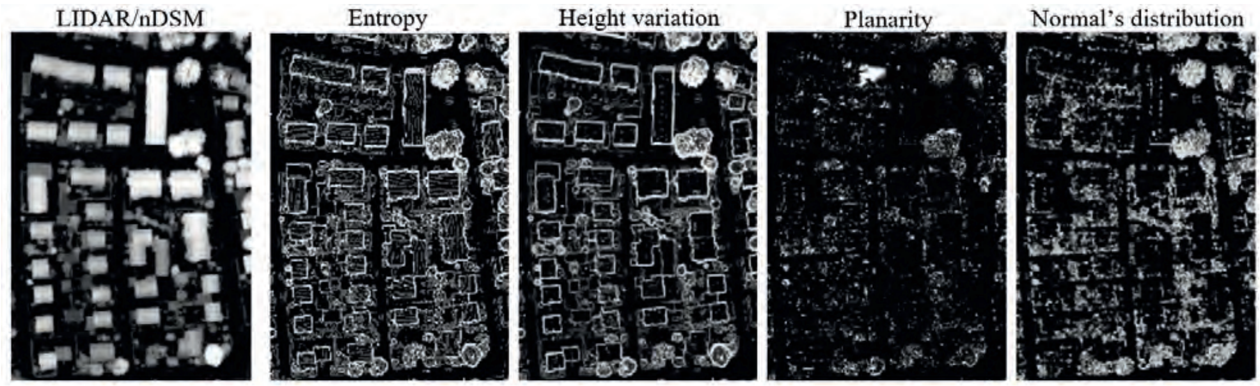
Besides the recent developments in image processing, advances in computer vision have promoted automated methods able to generate precise 3D models from overlapped multiple 2D imagery data derived from aerial platforms. Such methods apply a dense image matching (DIM) algorithm which extracts a textured dense 3D point cloud of a region or an object of interest. DIM is an affordable process compared to other approaches that use other types of sensorial data such as Lidar. In this area, numerous robust stereo image matching algorithms have been developed, each of which has its own advantages and limitations. A generic workflow for building detection and 3D modelling includes the following steps: i) collection of data and generation of proper features, ii) classification process, iii) building detection, iv) building roof segmentation, and v) 3D modelling and visualization.

GENERATION OF ADDITIONAL FEATURES

Depending on the data source employed, building detection techniques can be classified into three groups: i) ones that use airborne or satellite imagery data, ii) ones that exploit three-dimensional information, and iii) those that combine both data sources. However, the two main limitations of using information from multi-modal sources (e.g., Lidar and imagery data) are the additional cost of acquisition and processing, and the issues related to co-registration. For this reason, in real-life applications such as the cadastral ones, sometimes only one type of data is considered. To this end, several indices and features are calculated to efficiently distinguish buildings from the other urban objects such vegetation and ground. In this context, depending on the data used, the normalized difference vegetation index (NDVI) is calculated (when the NIR band is available in images) and the normalized digital surface model (nDSM) is calculated (when DIM or Lidar point clouds are available). However, additional features can be calculated and image-stacked, especially

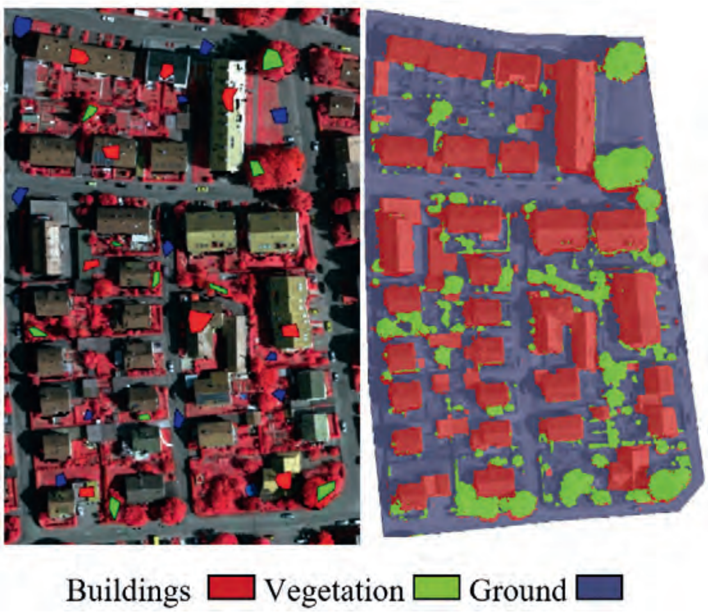


Generic workflow for building detection and 3D modelling.



▲ *Generation of additional features from Lidar point clouds.*

from Lidar point clouds, to further contribute to the classification performance. Such features come from a physical interpretation of the information, e.g. the entropy, the height variation, the planarity and the distribution of the normal vectors.

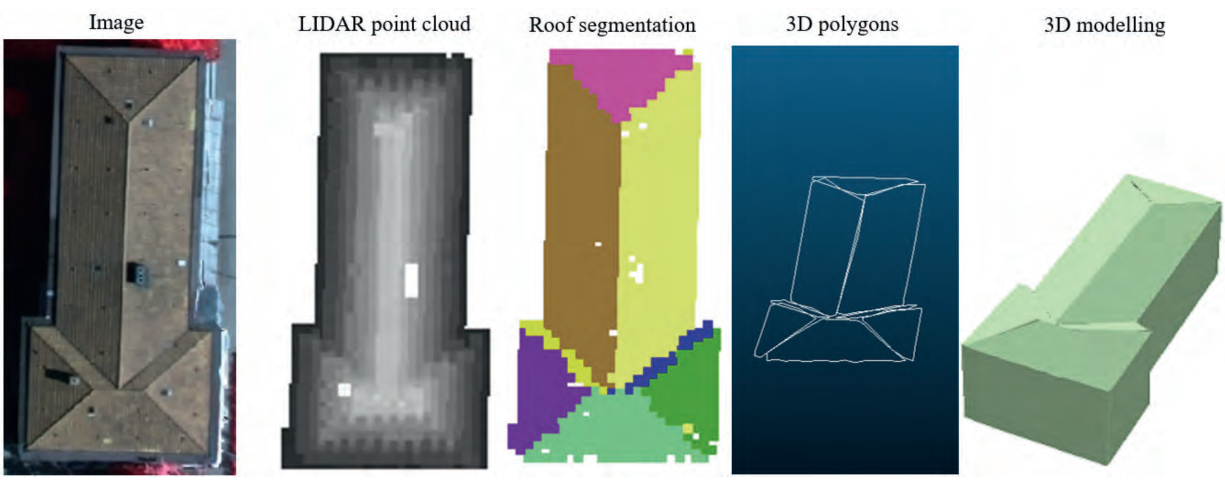


▲ *Collection of training samples for each class (left) and classification results through a CNN classifier (right).*

CLASSIFICATION AND BUILDING DETECTION

Usually, the methods of building detection are discriminated into the ones that apply a supervised machine-learning scheme and those that use a model-based approach. The main advantage of the machine learning approaches is that they are flexible and data-driven methods, requiring only training samples to successfully generalize the building properties and thus to perform an accurate classification. In contrast, model-based approaches consist of many parameters that need to be fine-tuned for each study area. Therefore, supervised learning paradigms provide higher generalization capabilities, i.e. robustness against data being outside the training set. Recently, in the context of machine learning, state-of-the-art algorithms like deep learning classifiers through convolutional neural networks (CNNs) have been efficiently applied for the building detection task.

In general, a CNN classifier has two main components: the convolutional layer and the classification layer. A convolutional layer



▲ *Building roof segmentation and 3D modelling.*

is essentially a network feature extractor that employs convolution filters (i.e. transformations) to the input data (image-stack features). These extracted network features are able to optimize the classification performance. Spatial coherency is an important element of the transformations involved in the convolutional layer. This is an important property of a deep CNN model since spatial characteristics significantly affect building detection accuracy. The aim of the classification layer is actually a supervised learning scheme with the capability of transforming the inputs from the convolutional layer into desired outputs, i.e. the labelled classes. Therefore, a CNN classifier, in contrast to a shallow machine learning method, first filters the input data in a way to maximize the classification accuracy and then performs the classification. The output of the CNN is a classified image on a pixel level, including information associated with the label of each class. Post-morphological processing is adopted to reduce classification noise, taking into consideration the spatial coherency property, i.e. through min operators followed by majority voting filters, etc. Finally, to evaluate the final building detection results, objective criteria are used such as the completeness, correctness and quality rates based on the TP, FP and FN entities, whereby TP stands for true positives (e.g. reference building pixels that were correctly detected), FP stands for false positives (e.g. building pixels that not exist in the reference dataset) and FN stands for false negatives (e.g. reference building pixels that were not detected).

BUILDING ROOF SEGMENTATION AND 3D MODELLING RESULTS

The extracted building boundaries from the classification process are slightly dilated in order to clip the raw Lidar or DIM point cloud. Then, for each 3D point cloud of each building, a building roof segmentation process is carried out. The most-used plane detection techniques from 3D point clouds are region growing, RANSAC and Hough methods. In fact, adaptive point randomized Hough transform (RHT) can extract satisfactory results, satisfying greatly the accuracy vs. computational time trade-off. For each detected plane, the corresponding boundaries are extracted to generate the associated 3D polygons. Once the normalized height values of each polygon vertex are available, the corresponding 3D building model can be extracted.

CONCLUSION

Automatic building detection and 3D modelling is a continuous, essential and crucial task for a variety of applications. Modern technologies support the development of a generic workflow. Two key emerging technologies are: i) various new sensors that can provide multiple information (e.g. multi/hyperspectral Lidar point clouds), and ii) cutting-edge methods such deep machine learning schemes. ◂

FURTHER READING

- Maltezos, E., Doulamis, A., Doulamis, N., Ioannidis, C., 2019. Building extraction from LIDAR Data applying deep convolutional neural networks. *IEEE Geoscience and Remote Sensing Letters* (GRSL), Vol. 16, pp. 155-159.

- Maltezos, E., Doulamis, N., Doulamis, A., Ioannidis, C., 2017. Deep convolutional neural networks for building extraction from orthoimages and dense image matching point clouds. *Journal of Applied Remote Sensing*, Vol. 11, 4, pp. 042620-1-042620-22.

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GIM INTERNATIONAL TALKS TO THOMAS HARRING, PRESIDENT OF HEXAGON GEOSYSTEMS

At the Forefront of the Digital Transition

Thomas Harring started in his position as president of Hexagon Geosystems and CEO of Leica Geosystems in early 2020. The year took a sudden and very unexpected turn when the outbreak of the COVID-19 pandemic threw a spanner in the works. However, Harring emphasizes that the geospatial industry should use the momentum of the 'new normal' to further accelerate the sector's ongoing transformation towards more customer-centric and autonomous digital solutions.

How would you summarize the current state of the geospatial industry?

Despite the undeniably terrible consequences of the current pandemic, the geospatial industry has not lost any of its importance and will continue to grow at an above-average rate. Based on their various experiences with remote working and workforce protection in the field and in the office, many organizations will go on the offensive, disrupting legacy processes and systems. Governments in particular can play a strong role by opening up their infrastructure to digital solutions and boosting new service opportunities. This situation has brought several key topics to the forefront, such as real-time office/field collaboration using digital tools, frequent remote progress monitoring, and increased demand for accurate and reliable digital realities. I believe we should use the momentum of the 'new normal' to intensify our ongoing efforts to transform the geospatial industry towards more customer-centric and autonomous digital solutions.

Which new challenges and opportunities is the digital transformation creating for surveyors?

In the geospatial industry, the digital transformation will accelerate the convergence of real and digital worlds to provide additional value for current and future customers. The geospatial industry is at the forefront to facilitate automation. The underlying technologies, such as the cloud, big data analytics, the internet of things (IoT), artificial intelligence (AI), edge computing and sensor fusion, will play an active role in expanding digitalization beyond IT, making the world more sustainable by providing fast, reliable and accurate decision support autonomously. Surveyors and other geospatial professionals will continue to benefit from digital reality capabilities by pairing domain expertise and leading technology.

The number of acquisitions reveals a clear growth strategy. How would you describe Hexagon Geosystems' ambition?

Hexagon's growth ambition is unchanged; we're expanding in our target markets with software, sensor and service-based solutions that create customer value. We're strengthening our competitive advantage through balanced organic and inorganic growth. Our technology and solution roadmaps provide a framework for defining which technologies and domain expertise will make us even stronger. In the Geosystems division, we recently acquired Geopraevent, a solution provider of alarm and monitoring systems used to protect critical infrastructure from natural hazards, which also uses our leading software and sensing solutions. Another recent example is Tacticaware, a provider of Lidar-based 3D surveillance software used to monitor and protect critical infrastructure and buildings. Together with our new Leica BLK247, we can now offer our customers an integrated end-to-end security surveillance solution.

The surveying equipment manufacturing business is highly procyclical (i.e. strongly linked to GDP fluctuations). How is your company dealing with this?

As a global company, we are repeatedly exposed to gross domestic product fluctuations to varying degrees. To break or alleviate the cyclical dependency, we always do what made us strong in the past: we stimulate demand for productivity solutions with innovative software and sensing solutions, regardless of whether we sell them or provide them as a service. Our solutions make customers more productive and successful and thus give them transparent, visible payback. A current example is the Leica GS18 I GNSS-RTK-Rover, which with its visual positioning technology allows users to reach previously inaccessible or obstructed points, to check the quality of the data while on site and to extract points later in the office.

Suppliers often regard themselves as solution providers, but many surveyors adopt a 'mix and match' approach and select independent software to process sensor data. What is your view on this?

There have been discussions in the geospatial industry regarding open, closed and selectively open architecture related to sensor-data processing software for many years and these discussions are intensifying. Our belief is unchanged that customers want to have choices and decide based on their needs. However, there is no guarantee that a

multi-vendor solution will integrate seamlessly or perform optimally. Of course, the task of the whole geospatial industry is to educate customers about new possibilities. Therefore we continue to take independent software providers with us as far as possible on the shared journey into the future; we have worked successfully with many of them to integrate new scanning, photogrammetry or radar workflows in their offering as well as to use the edge computing possibilities of our sensing solutions with their software suites.

THE GEOSPATIAL INDUSTRY WILL TRANSFORM TOWARDS MORE CUSTOMER-CENTRIC AND AUTONOMOUS DIGITAL SOLUTIONS

The evolution of 5G is expected to bring many new opportunities for the surveying industry. How is Hexagon responding to 5G availability?

I would say the evolution of 5G technology brings additional opportunities for the geospatial industry in two respects: the deployment of 5G networks needs geospatial solutions, and the use of the network offers unlimited possibilities for business expansion. 5G telecommunication infrastructure must be secure, reliable and interoperable to handle the volume of applications and services. Accurate and reliable geospatial data is essential for the correct positioning of the base stations supporting denser networks. And in terms of business expansion in the geospatial industry, the possibilities are obvious – the 5G technology works like glue to network the individual sensors, speeding up data transfers and reducing latency. This will boost the convergence of the real world with the digital realities and increase the customer value of solutions such as the HxDR platform and all of Hexagon's other smart solutions that support autonomous decisions remotely and in real time.

GNSS technology is key within the geospatial industry. Which developments do you foresee in GNSS technology and services over the coming decade?

GNSS has become the leading positioning technology in numerous applications and the pace of technological advancement in the geospatial industry over the past 30 years has been impressive. Simply speaking, three different GNSS solutions have been introduced to date: the high-end RTK rovers, the handheld GIS data collectors and the machine control systems. Today, our handheld GIS data collectors have smart positioning technologies, such as with HxGN SmartNet included, providing professionals with accurate data and backup systems when connectivity issues occur. As positioning of objects in the real world is becoming increasingly important, the spread of GNSS solutions is also increasing. Regarding RTK rovers, we are proud to offer our customers leading innovative solutions such as the Leica GS 18 T and the recently released Leica GS 18 I with its leading visual positioning technology. And let's not forget all the developments in our software offerings to support these exciting sensor fusion and edge computing capabilities. What's next? Trust us, our teams are already working on it!

THE BENEFITS OF THE GEOSPATIAL INDUSTRY ARE BECOMING MORE AND MORE VISIBLE BEYOND THE GEOSPATIAL EXPERTS

Combining airborne cameras and Lidar sensors is the new trend in airborne mapping. How will this development impact on how the environment is mapped from above?
Since we launched the Leica CityMapper some years ago – the world's first hybrid airborne sensor providing both oblique and multispectral nadir imagery and Lidar data – the urban mapping and creation of 3D geospatial data for smart city applications has reached new levels. The advantages – such as reduced collection costs as two datasets are collected in one flight, reduced manual edits as fused data improves automatic modelling and many more benefits – support efficient updates of geospatial base layers for fast-changing urban environments. Last year we launched the Leica CityMapper 2 and customers benefit from digital surface and elevation models as well as qualitative data on vegetation, street information, built-up areas and land use. In addition, they have access to 3D information in the form of GIS-ready buildings for planning purposes and 3D meshes for visualization. Mapping is becoming more and more efficient, providing Hexagon's smart solutions with reliable and fresh geospatial mapping data.

How is the role of surveyors changing in the context of building information modelling (BIM)?
In the digital world, methods which previously existed separately – such as GIS or BIM – are increasingly converging. Data analysis is becoming more and more enhanced as AI capabilities help to deliver business insights that are available 24/7 and networked. Day-to-day work is being automated and – if coded properly – fewer errors occur. The blurring boundaries

between the AEC (*architecture, engineering and construction, Ed.*) sector and the geospatial industries reinforce the need for surveying capabilities throughout the whole life cycle of infrastructure and buildings. The role of scanning and imaging technologies in accurate, reliable positioning and measuring as well as in planning and digitally simulating the real world is forcing all relevant professions to learn about the use of geospatial data. Surveyors have been, and will remain, critical for the adoption of geospatial technology in these life cycles.

Which other changes do you predict for the surveying profession over the coming years?
Geomatics as an applied science and a professional discipline is often described as an integrated approach to the measurement, analysis, management and visualization of geospatial data. Companies operating in the world of geomatics are facing ongoing innovation challenges due to rapidly changing technologies, such as Lidar, the cloud, IoT, artificial intelligence and many others. IT expertise is becoming increasingly important, and – as I mentioned earlier – surveying and geomatics professionals will continue to benefit from their geospatial capabilities in pairing domain expertise and leading technologies. Clearly, we must continue the dialogue with academia all over the world to engage strongly with the education of the future geospatial professionals. Last year, we celebrated 200 years of geomatics in Switzerland, an anniversary which demonstrates the impact and the importance of surveying. We see lots of new opportunities for surveyors and hope to celebrate our combined rich history with them for many years to come.

Do you have a final message for the geospatial community?
The benefits of the geospatial industry are becoming more and more visible beyond the geospatial experts and that is why expectations of us are increasing rapidly. Hexagon remains fully dedicated to this industry and will continue to drive the adoption of technology and customer-centric applications towards autonomous connected solutions. We are geospatial enthusiasts who believe in the future of the geospatial industry and aspire to be role models, leading by example and demonstrating what can be done. ◂

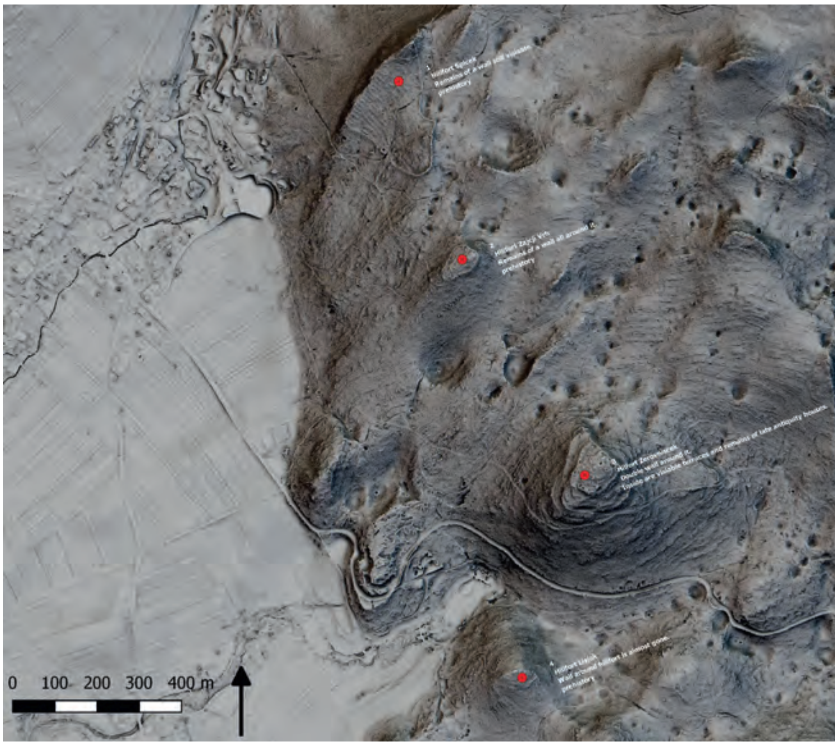
ABOUT THOMAS HARRING

Thomas Harring became president of Hexagon Geosystems and CEO of Leica Geosystems in February 2020. He was appointed as COO/CFO of Hexagon Geosystems and Leica Geosystems in 2011, and before that he held various management positions at Leica Geosystems. Prior to joining Leica Geosystems in 2003, Thomas Harring spent many years working as a senior management consultant at an international consultancy firm in Düsseldorf and served as academic counsel at the Technical University of Cottbus (Germany). He holds a diploma degree in technically oriented economics from the Technical University of Stuttgart.

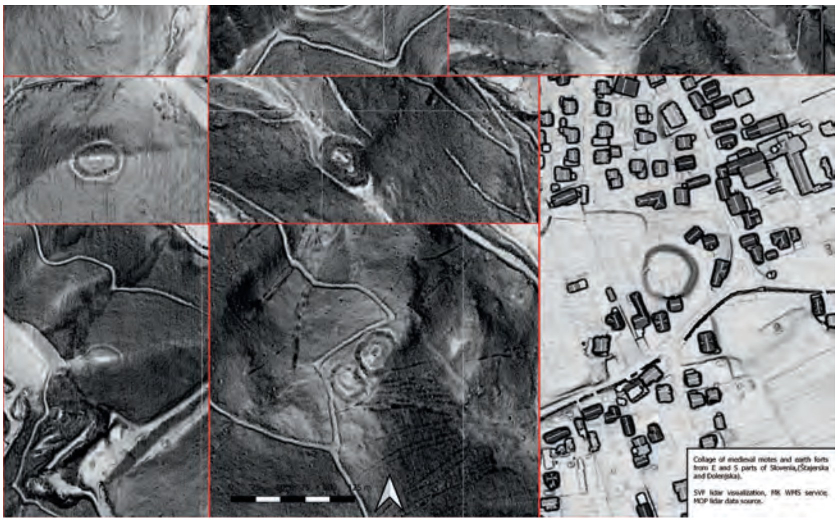
Lidar Data – A Perfect Tool for Archaeology

Today, usage of Lidar data in archaeology is almost a must when researching landscapes and archaeological sites. But in my seven years' experience of using airborne Lidar data, I have come across a few obstacles that are making it look exotic and perhaps even threatening.

The first obstacle is Lidar data that is put behind a paywall – despite in effect being data that has been paid for by taxpayers' money. Open data is more inclusive, and it stimulates more research. Luckily, a lot of countries around the world are releasing Lidar data as open data, and I hope the trend will continue in the future so that this obstacle will one day disappear.



▲ *Line of known prehistoric and late antiquity hillforts as seen on mixed Lidar visualization. Above Cerkniško lake, Notranjska region, Slovenia. (Image courtesy: Jošt Hobič)*



▲ *Mediaeval mottes and early mediaeval castles from various parts of Slovenia, found with help of Lidar data. (Image courtesy: Jošt Hobič)*

I immediately fell in love with airborne Lidar data for archaeological sites the very first time I saw a visualization, since it was not only beautiful but also very useful for examining and researching landscape through another medium. At the time I was completely new to the GIS environment – studying archaeology back then had not prepared me for it. But I persisted and I learned a lot, mostly through trial and error and with the help of the GIS internet community. And this highlights the second obstacle: GIS is complicated. Most people who want to use Lidar data for archaeological research stop because making it 'work' is just too complex, especially if they only need visualizations for one archaeological site. And this is what I mean by the usage of Lidar data being 'exotic'. This exclusivity often results in Lidar data not being used in big projects and excavations, even though its use could help to answer some questions and support planning decisions.

The third obstacle is a misconception about what Lidar data is. It is not a magic wand that will show us every archaeological site in a landscape and answer all our questions about the landscape's history. Instead, because Lidar data captures all the surface features, we need to consider that it will also contain a lot of 'non-archaeological' features. Like any other archaeological record, this often leads to more questions than it answers. But for me, those questions are what make things so interesting.

As I see it, all three obstacles can be solved by offering more GIS courses during university degrees, providing online courses and tutorials, and giving open access to various pre-prepared Lidar visualizations. The first two are longer-term solutions and I must say there are already some positive changes in archaeology departments here in Slovenia and probably around the world. But the fastest and easiest way to open up Lidar data is by publishing pre-prepared visualizations, as WMTS services for example. This reduces the complexity of GIS workflows and of obtaining data (whether open or closed).

I have personally experienced just how much impact proper visualization can have on the usage of Lidar data. When the Registry of Slovenian Cultural Heritage GIS viewer was updated in 2018, we also added Sky-view factor (SVF) visualization of Slovenian Lidar data. Feedback from the archaeological and heritage sectors was mostly very positive. But I am most proud that we engaged people who are interested in archaeology and the general public. Because over 50% of Slovenia is covered by forests, lots of areas were completely unresearched. In the last two years, lots of people have sent us details of hundreds of new archaeological sites that they've found with the help of Lidar visualization; there's so much new information flowing in that regional archaeologists cannot keep up with it all. There are also some very interesting projects going on in the UK (e.g. Beacons of the Past – hillforts in the Chilterns landscape) that use Lidar data to engage and actively involve people in researching and discovering archaeology in their surroundings.

Some members of the archaeological community fear that this kind of open-access data creates a threat by highlighting more targets for people with metal detectors looking to illegally excavate and sell archaeological finds on the black market. In my opinion, we need to tackle this issue not by closing the archaeological door, but by educating the general public and opening up the discipline so that archaeological heritage becomes everyone's heritage, with a shared responsibility to keep it safe and maintain it. The visualization of Lidar data forces us heritage professionals to come down from our ivory towers. By presenting landscapes and archaeological sites in countless different and often colourful ways, it has the power to captivate many people. Lidar has proven to be a perfect tool for making archaeological research less complex and making archaeology more open. That's more than enough for me!

ABOUT THE AUTHOR

Jošt Hobič is an archaeologist with over a decade of experience in commercial archaeology. In his free time, he does volunteer work on various public archaeology projects. He is currently working at the Slovenian Ministry for Culture on an EU-funded project with the main goal to improve access and open GIS data about immovable cultural heritage. He is currently in the third year of his PhD in archaeology at the University of Ljubljana, Slovenia.

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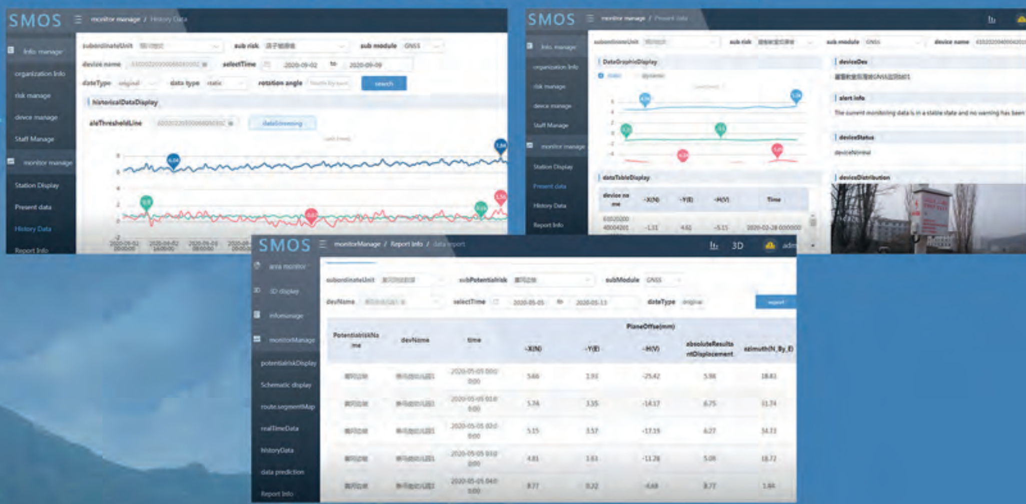

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A USER'S PERSPECTIVE ON OPTICAL EARTH OBSERVATION SENSORS

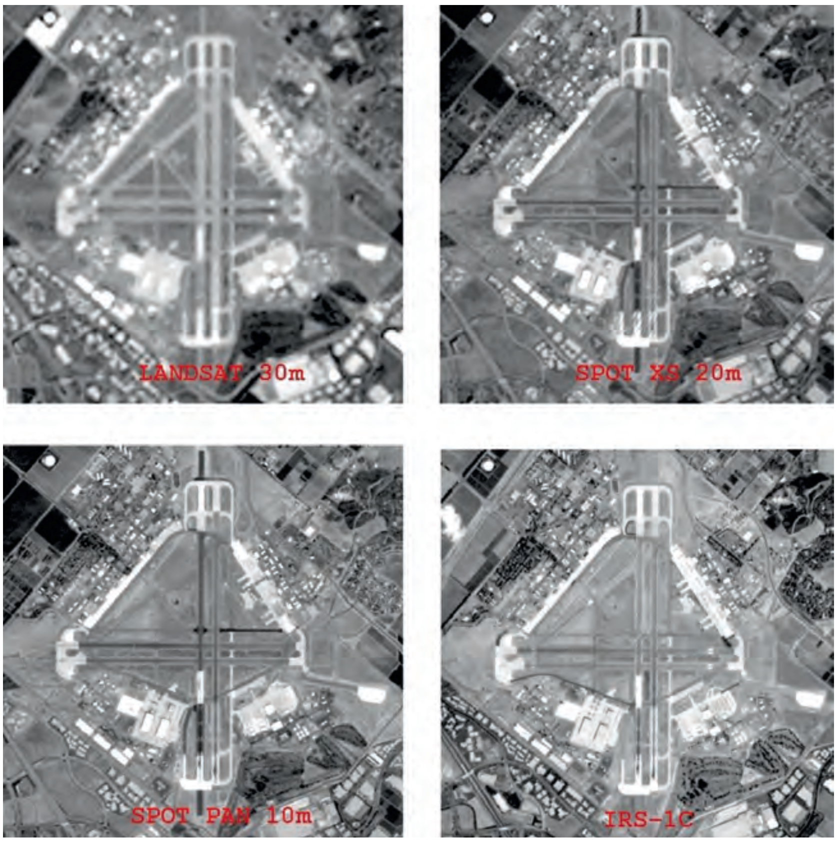
Understanding Spatial Resolution

Earth observation (EO) from space is important for resource monitoring and management. The performance of optical EO sensors is determined by four resolutions: spatial, spectral, radiometric and temporal. In this article, focusing on spatial resolution and manufacturers' specifications, the author issues a wake-up call to users – encouraging them to better understand the abilities of EO sensors for object recognition – and provides a means to compare their performance.

Civilian systems have had sub-metre spatial resolution since Landsat-1 was launched in 1972. With 80m, it was almost a spatial resolution revolution! The description in the literature of spatial resolution differs. It is usually given as a single number, e.g. 30m for Landsat 7, referring to an area of 30mx30m on the ground (Figure 1). To explain spatial resolution, the configuration of a pushbroom imaging sensor consisting of a linear array is considered. The linear array is made up of a number of detectors, which are optically isolated (Figure 2).

MANUFACTURER'S PERSPECTIVE

The instantaneous field of view (IFOV) is an angular measure and determines the footprint from which an individual detector, usually a charge coupled device (CCD) element, captures radiance. The footprint is thus the projection of a single detector on the ground through the lens system. Manufacturers call it spatial resolution, but instantaneous geometric field of view (IGFOV) would be a better term. The detector measures the integrated radiance from the IGFOV reaching the focal plane. IGFOV is also called 'resolution element'/pixel, although there is a slight difference between both. Pixel (picture element) is the smallest unit of a digital image which is assigned brightness and colour. Its size does not necessarily equal IGFOV, since pixels can be generated by resampling the original data. For example, an image from a sensor with an IGFOV of 6.25m collects four samples over a distance of 25m. During postprocessing this may be resampled to 5m resulting in five pixels over 25m. Manufacturers call the resampled distance the ground sample distance (GSD). The IFOV characterizes the sensor, irrespective of the altitude of the platform. The field of view (FOV) is the total view angle that defines the swath. So, the spatial resolution of 20m for SPOT HRV means that each CCD element collects radiance from a ground area of 20mx20m.



▲ *Figure 1: An airport surrounded by varying land uses and captured by four EO sensors with different spatial resolutions – Landsat 7 (30m), Spot (20m), Spot (10m) and IRS (5m) – shows differences in identifiability of objects; note the different time stamps of image capture. (Image courtesy: Land Info Worldwide Mapping, USA)*

USER'S PERSPECTIVE

Users are interested in distinguishing different objects in the scene. For them, spatial resolution refers to identifying adjacent objects with different reflectance/emittance in the scene. When the resolution of a SPOT HRV is 20m, one intuitively assumes that the size of the smallest identifiable object is 20m. However, not all footprints of 20mx20m are identifiable in SPOT imagery. On the other hand, one may identify high-contrast objects smaller than the IGFOV, such as roads and railways, because of their linear structure. Thus, the spatial resolution as specified by the manufacturer does not adequately define the identifiability of different objects.

MODULATION TRANSFER FUNCTION

An object can only be distinguished from its surroundings if there is a brightness or colour difference – called contrast – between them. The greater the contrast, which is the difference in the digital numbers (DN) of an object and its surroundings, the easier the object can be distinguished. For example, a white ball on a green lawn can be distinguished more easily than a green ball on a green lawn. A minimum contrast, called the contrast threshold, is required to detect an object. To compare targets with different illumination levels, the contrast is normalized with total illumination; this is called contrast modulation (CM). Sensor characteristics, atmosphere, platform jitter and many other factors reduce contrast. The modulation transfer function (MTF) expresses the reduction in CM from object space to image space: MTF equals CM in image space (CM_{is}) divided by CM in object space (CM_{os}) (see Equation 1 in Table 1). The MTF is a critical performance parameter of the sensor, but it only partially determines the identifiability of an object.

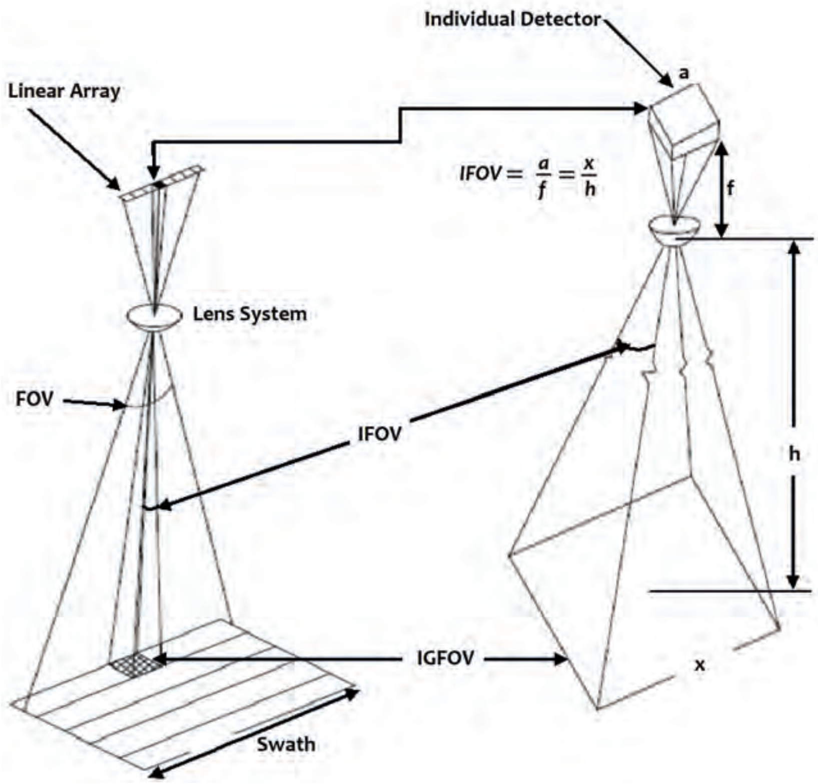
RADIOMETRIC RESOLUTION IS OFTEN CONFUSED WITH THE NUMBER OF QUANTIZATION BITS

NOISE

Noise is produced by detectors, electronics and digitization, amongst other things. To recognize an object, the radiance difference between the object and its surroundings should produce a signal which is discernible from the noise. This is called radiometric resolution, which is the smallest radiance difference that can be detected by the sensor. At the sensor, it is represented as the noise-equivalent radiance change (NEΔL). This is defined as the change in the input radiance which gives a signal output equal to the root mean square (RMS) of the noise at that signal level. If the signal generated from the radiance difference between the target and its surroundings is less than NEΔL, distinguishing an object is like looking for a needle in a haystack. The higher the radiometric resolution, the more sensitive a sensor is to detect small differences in the reflected or emitted energy. Radiometric resolution depends on the signal-to-noise ratio (SNR), the saturation radiance setting and the number of quantization bits. In general, a sensor with a higher SNR can better distinguish an object. Radiometric resolution is often confused with the number of quantization bits. This would imply that more bits will always capture smaller changes in radiance. This is not true (Joseph, 2020). Nevertheless, the more bits there are, the better the dynamic range is, which is advantageous when sensors need to cover the entire Earth from very dark areas (such as sea surfaces) to very bright areas (such as glaciers) without changing system gain settings.

FIGURE OF MERIT

A fair comparison of object detectability in images of various EO sensors operating in the visible and near-infrared spectral bands requires a Figure of Merit (FOM). Users expect high target-discrimination capability, which means that the sensor can discriminate small objects with a low radiance difference. From the above discussion it can be inferred that target-discrimination capability depends on the object contrast, the MTF and the noise-equivalent radiance. To minimally reduce



▲ *Figure 2: A pushbroom sensor images a ground strip on a linear array of detectors; the ground swath depends on the length of the array; IFOV (in radians) equals the size of the individual detector (a) divided by the focal length (f).*

object space contrast during imaging, one should choose a sensor that gives the highest MTF. One would also want detection of small radiance changes, which requires a sensor with a high radiometric resolution (lowest value for NEΔL). An FOM which combines minimal loss of object space contrast and detection of small radiance changes is the ratio of MTF at IGFOV to noise-equivalent radiance at a defined reference radiance level. Since SNR can be dependent on the input radiance, it is necessary to specify a reference level (Ref) for NEΔL. Reference radiance at 90% and 10% of saturation value could be adopted. For sensors operating in the thermal band, the temperature difference (NEΔT) is generally expressed at 300K. The FOM is given as in Equation 2 in Table 1. To make FOM independent of units, one may use the SNR value at the reference radiance instead of radiometric resolution. Since the system with the highest SNR has better performance, the FOM can be rewritten as in Equation 3 in Table 1.

EQUATION	
1	$MTF = CM_{is} / CM_{os}$
2	$FOM = MTF_{IGFOV} / NE\Delta L_{Ref}$
3	$FOM = MTF_{IGFOV} \times SNR_{Ref}$

▲ *Table 1: Equations for MTF and two Figure of Merit (FOM) measures.*

CONCLUDING REMARKS

The manufacturer's specification of spatial resolution alone does not reveal the ability of an EO sensor to identify the smallest object in image products. In general, the higher the spatial resolution is, the more details can be identified in imagery. However, when the manufacturer's specification of spatial resolution of sensors is close by, FOM provides a measure for selecting the sensor with the best target discrimination. Furthermore, manufacturers' specifications are based on the laboratory evaluation of sensor performance. Therefore, based on post-launch calibration of the sensor, FOM should be evaluated at the product level users deal with. ◂

FURTHER READING

The above is only one aspect of understanding EO sensor specifications. Other aspects can be found in: Joseph, G. (2020) How to Specify an Electro-optical Earth Observation Camera? A Review of the Terminologies Used and its Interpretation. *Journal of the Indian Society of Remote Sensing*, 48: 171"

ABOUT THE AUTHOR

George Joseph joined the Indian Space Research Organization (ISRO) in 1973 and retired as the director of the Space Applications Center in 1998. He introduced CCD technology for Earth imaging systems in India. He was instrumental in developing a variety of electro-optical sensors for ISRO's Earth Observation programme, such as IRS and INSAT. He is the pioneer of satellite-based imaging sensors in the country and was president of ISPRS Technical Commission 1 (1996-2000).
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5 Questions to... Richard Cooke, Director of Imagery, Esri

Esri recently made headlines in the geospatial industry when it announced the acquisition of nFrames, the innovative Germany-based developer of software for 3D reconstruction from images. To learn more about Esri's recent takeover, we spoke to Richard Cooke, director of imagery at the world-leading company in GIS software.

What were Esri's main considerations when acquiring nFrames, a relatively small photogrammetric company that is highly specialized in 3D modelling of imagery?

We are delighted to bring the nFrames staff and products into Esri, as this will enhance our existing 3D modelling and photogrammetric capabilities. The main consideration was to enhance our ability to help our customers perform highly accurate mapping and reality-capture workflows within the Esri platform by adding technology that allows for greater scale and produces very high-quality and accurate results.

Many companies are active in the field of photogrammetry and offer similar solutions as nFrames. How does nFrames offer Esri something extra?

In most cases, the data produced by photogrammetric processing needs to be used in a broader set of GIS and location workflows. So the simplest motivation is to give our customers who are creating or consuming 2D and 3D data a seamless workflow and user experience. We will accomplish this by integrating the nFrames technologies into the Esri platform. This will allow users to integrate high-resolution 3D content into their systems of record, but also to use all of our visualization tools to share the information with all of their stakeholders. Secondly, we believe that spatial analytics are becoming more multidimensional, so having the ability to create authoritative 2.5D and 3D data that can be used for analytics is essential to enhancing the spatial workflows of the future. This will also require that datasets can be built from the co-registration of data from collection platforms from nadir to oblique and, ultimately, street view.

nFrames is a spin-off of the University of Stuttgart, Germany. Were the possibilities of collaborating with that university a trigger in acquiring nFrames?

It is well known that the University of Stuttgart is a centre of excellence for photogrammetry, so the fact that nFrames rose out of this stellar institution gives their technology very strong credibility. We will definitely want to leverage their heritage from the university to continue our contribution to research in new approaches to maintain leadership in the areas of 3D reconstruction and photogrammetry. Esri has a strong history of working with universities and research institutions around the world on conservation and technology innovation in the disciplines most important to GIS users, and this will be important for us as we bring nFrames into the Esri family.

What is the profile of the current nFrames software user base, and does the acquisition fit into a larger Esri strategy to expand its product base?

The current nFrames customers embrace the product's capabilities to utilize large aerial collections to create foundational 3D content for their projects. Current customers are executing workflows in the areas of mapping, survey, cadastre, change monitoring and infrastructure planning. We will maintain these focus areas, but we also plan to expand these capabilities into existing sectors Esri serves, such as architecture, engineering and construction (AEC), national governments, utilities, and natural resources, where we plan to use the nFrames capabilities to deliver foundation 3D content that integrates into existing customer workflows built on the Esri platform.

Since the introduction of semi-global matching, photogrammetry has made fascinating progress and enjoyed significant growth spurts. Which social and technological advancements will further stimulate photogrammetry over the next five years?

The next five years will see an expectation of 3D content within traditional GIS workflows such as mapping, planning, monitoring and sharing. We expect customers to build and maintain 'digital twins' as a key element to their operations. Authoritative 3D content is essential for these new workflows as well as the ability to perform analysis within a 3D world and share the results with multiple clients in 3D. Beyond that, we believe the ability to take our advanced analytics and artificial intelligence/machine learning (AI/ML) approaches and perform those on the high-resolution 3D meshes will drive even greater innovation in the photogrammetric techniques required to give users the best quality and accuracy for performing those analytics. For example, highly accurate feature extraction and attribution from the mesh as opposed to traditional approaches against 2D and 2.5D data sources. ◂

We asked Richard Cooke some further questions. Read the full Q&A on our website: gim-international.com.

About Richard Cooke

Richard Cooke joined Esri in September 2018 as the director of global remote sensing and imagery, the business team focused on helping customers apply the ArcGIS platform and tools to manage, analyse and share insights from their remote sensing and imagery data collected from satellites, aircraft, drones or terrestrial sensors. Cooke has around 30 years of experience in the fields of computer vision, remote sensing and geospatial intelligence.

GLTN Professional Cluster Activities and FIG Commission 7 Annual Meeting

FIG and the Arab Union of Surveyors are currently leading the UN-Habitat/Global Land Tool Network (GLTN) professional cluster. During this term, three activities are in focus: Urban Rural Land Linkages, Valuation of Unregistered Land, and Arab Land Initiatives. The work plans of these activities have been amended due to the fact that since March all face-to-face events have been cancelled. The focus of the Valuation of Unregistered Land initiative is to produce a practical manual that operationalizes the 2018 GLTN 'Valuation of Unregistered Lands: A Policy Guide' and creates a robust, practical framework for valuation within this difficult sector. Valuation is a critical element of functioning land administration systems and this new manual should provide a key enabling tool for prospective land-based financing and fair compensation initiatives. FIG Commission 9 on Valuation is leading this project. The expert working group is close to finalizing a pre-consultation draft document. After consensus, an open, global online consultation will take place. An online masterclass will form part of the consultation process in September/October and a final reviewed manual is expected to be ready for delivery to GLTN in December 2020. A meeting in Cairo in February 2020 focused on Arab Land Initiative Projects and it was attended by the nine organizations with which GLTN has signed contracts. In mid-June, Lebanese University organized an online workshop on 'Towards a Postgraduate Programme in Land Governance Serving the Needs of Lebanon and Other Middle Eastern Countries'. Rafic Khouri, in his capacity of senior consultant to the initiative, is currently reviewing the translation of a trilingual glossary about land-related terms (English, French and Arabic).

Many development and research institutions are now working towards strengthening Urban-Rural Land Linkages which is the topic of the third activity. These institutions (including World Bank, OECD, FAO, IFAD, UN-Habitat, IIED, UNFCC and EC) have issued a call highlighting the urgent need to plan, design and implement integrated policies and programmes within the urban-rural continuum as compared to the traditional binary approach of focusing only in urban or rural contexts. There is a need to develop a conceptual framework on urban-rural land linkages. FIG Commission 7 on Cadastre is leading the project, with the support of Commissions 8 and 9. A draft has been produced and an online consultation strategy has been developed with experts in line with COVID-19 restrictions. Originally, consultations and debate were planned to take place at the yearly FIG Commission 7 meeting – which along with so many other events will be transformed into an online meeting. Instead workshops in English, French and Spanish are being planned. A final Urban-Rural Land Linkages framework is planned to be published by the end of the year.

The FIG Commission 7 Annual Meeting will be held online between 20 and 22 October and is open for all who are interested. The theme of the meeting is 'Building community resilience: Urban-rural land linkages and strategies to deal with COVID-19'. A central part of the online event will focus on workshops to discuss the GLTN draft urban-rural land linkage framework currently under development.

More information
https://www.fig.net/organisation/comm/7

IAG Commission 1: 'Reference Frames'

Commission 1 'Reference Frames' of the International Association of Geodesy (IAG) was originally established within the new structure of IAG in 2003 (IUGG XXXIII General Assembly, Sapporo), with the mission to address, coordinate and promote the study of scientific problems related to the establishment of Earth reference frames. Its commencement marked a forward-looking perspective for the geodetic exploration of the Earth system by recognizing the fundamental role of reference frames in the determination of the geometry, gravity field and rotation of the Earth (and their evolution in time). Those three elements constitute the main pillars of geodetic science which are intrinsically linked to each other and they jointly change in response to the dynamic character of our planet. The monitoring of these elements and their exploitation for Earth science applications cannot be achieved without the access to precisely defined reference frames that are delivered by space geodetic techniques, yet the realization and integrity of such frames pose significant challenges of growing complexity as the accuracy (and volume) of space geodetic data increases.

SCOPE AND OBJECTIVES

Commission 1 activities and objectives deal with the theoretical and operational aspects of how best to define reference frames and how they can be used for practical and scientific applications at different spatio-temporal scales on the deformable Earth. The relevant applications cover all aspects related to location and the study of location-based phenomena, including satellite navigation and orbit determination, high-accuracy positioning and mapping, geospatial information management, environmental and climatic modelling, etc. Of high priority to the Commission's work is the development of modern reference frames for an improved understanding of Earth dynamics due to tectonic plate motion, sea level change, glacial isostatic adjustment, ice melting, non-tidal loading, geocentre motion, earthquake deformation, local subsidence and other crustal displacements.

STRUCTURE AND LIAISONS

In order to streamline and appraise the research efforts towards the above objectives, Commission 1 is organized into four sub-commissions (see Figure 1) with an advisory Steering Committee consisting of the Commission 1 president and vice-president, the chairs of sub-commissions, representatives of IAG services and other members-at-large from the international geodetic community. More than 150 scientists from 62 countries are currently affiliated with 20 different working groups and one study group that have been established under the auspices of Commission 1 for the current four-year period (2019-2023).

Commission 1 closely interacts with the other IAG commissions and services, the Inter-Commission Committee on Theory (ICCT), the newly established Inter-Commission Committee on Geodesy for Climate Research (ICCC), and the components of the Global Geodetic Observing System (GGOS) where reference system aspects are of concern, to address related problems for the realization of celestial and terrestrial reference frames in conformity with present and future accuracy needs. Commission 1 is also linked with the IUGG/COSPAR joint Sub-Commission B2 (International Coordination of Space Techniques for Geodesy) under the aim to develop links and coordinate the work between various groups engaged in the field of space geodesy and geodynamics.

More information
https://www.iag-aig.org/iag-commissions
https://com1.iag-aig.org

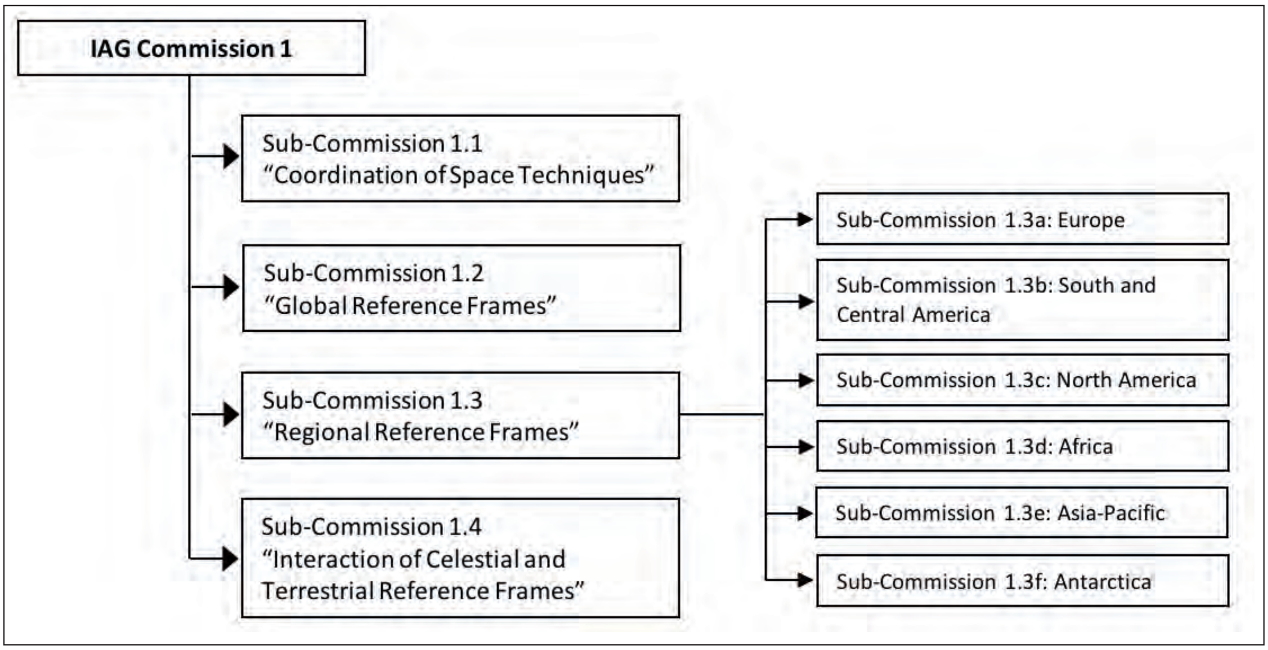

Figure 1: The basic structure of IAG Commission 1.

ICA in the Year of the Coronavirus – More Maps and Changing Activities

Over the last six months, the world has experienced an extraordinary situation: our daily life has been impacted by a tiny virus. It has resulted in a pandemic, where the virus has dispersed in most regions of the globe with varying speed. To describe how the disease spreads around the world, it is natural to use maps. This has resulted in a large amount of new cartographic visualizations which aim to describe development and impacts of the COVID-19 disease in different countries and regions. The constantly changing situation has made such visualizations well suited for online media.

A lot of excellent cartographic presentations have been produced and used in combination with other graphic illustrations. However, in this period we have also seen many examples of 'coronavirus maps' which have made it evident that the producers of the maps lack basic cartographic knowledge. This may result in misleading maps. Today, it is easy to make a thematic map using various drawing tools on a computer. In this situation it is important for the cartographic community to reach out to all those mapmakers and support them with the basic knowledge on how data should be presented properly in a map. The ICA Executive Committee and Commissions have tackled this issue and are working on ideas and plans to better educate and inform people responsible for such map products (e.g. through webinars or direct contacts with the media).

Like most other organizations, the coronavirus has also influenced the activities of ICA. For the first time in the 61-year history of ICA, a two-day meeting of the Executive Committee was accomplished 100% through digital channels. If there is no dramatic change in the situation, a first joint meeting between the Executive Committee and the 27 commission chairs will also be arranged in a digital manner in October.

Another notable development has been the recent establishment of a new ICA Working Group on Digital Transformation of National Mapping Agencies. The group will be chaired by Bin Jiang/Juha Oksanen. Moreover, the recently installed Working Group on the History of ICA has now found a chair (ICA News editor Igor Drecki) and started work.

In view of the pandemic's effect on ICA activities, here is a short update on upcoming events:

- EuroCarto 2020 has been postponed as a physical conference and is now going to take place in Vienna, Austria, from 17-19 September 2022. EuroCarto 2020 was held as a free-of-charge virtual event in the week of 21-25 September 2020.
- 15th ICA Conference on Digital Approaches to Cartographic Heritage / 22nd Conference of the Map & Geoinformation Curators Group which was scheduled for 24-26 September 2020 is postponed until spring 2021.
- 23rd ICA Workshop on Map Generalisation and Multiple Representation (ICAgen2020) is scheduled for 5-6 November 2020. Depending on the status of the coronavirus, the event will either take place entirely at the venue, or partly at the venue and partly online (hybrid), or fully online.
- 16th International Conference on Location Based Services, scheduled for 11-13 November 2020, is postponed to 2021.
- AutoCarto 2020, which was originally scheduled for May 2020, will now be held as virtual events from 17-20 November, together with pre-conference workshops.
- SilkGIS2020 is scheduled to be held in Ghent, Belgium, from 16-17 December 2020. This meeting was postponed from July 2020.
- Atlases in Time – National and Regional Issues was first postponed from April until October 2020, and is now rescheduled for 21-24 April 2021.
- 8th International Conference on Cartography and GIS is postponed from 2020 to 14-19 June 2021.
- We sincerely hope that it will be possible to hold the 30th International Cartographic Conference in Florence, Italy, from 19-23 July 2021 as planned.
- 20. Kartographiehistorisches Colloquium is postponed from 2020 until 1-4 September 2021.
- ICA Workshop on Analytical Reasoning: Cartography, Visualization, Design is postponed from 2020 to 14 September 2021.

Of course, all these new dates are subject to the development of the coronavirus situation and the travel restrictions for participants, meaning that further changes might be necessary. For current information on the situation, please always check the ICA calendar.

For more comprehensive information about ICA activities and events, readers can refer to ICA News, edited by Igor Drecki. The latest issue (#74) is out now. Additionally, readers who have interests in maps and cartography can also take a look at the archive of eCARTO news. The website, which embraces a wide variety of map/cartography-related resources, is edited by David Fraser, a retired professor of RMIT University Melbourne.

By Terje Midtbø

More information
https://icaci.org/calendar/
https://icaci.org/ica-news/
https://icaci.org/ecarto-news-archive/

The 2020 Edition of the XXIV ISPRS Congress

The ISPRS XXIV Congress was initially planned to be held from 14-20 June 2020. Due to the COVID-19 situation and its impact on international travel, the ISPRS Council decided to postpone the Congress to 4-10 July 2021. Nevertheless, the paper submission and reviewing process was nearly completed when the decision was taken. As it seemed scientifically impossible for an innovative scientific community to wait to present and publish papers submitted in February 2020 until a Congress taking place 18 months later, ISPRS decided to create two editions of the XXIV Congress:

- a digital 2020 edition with a three-day virtual event, which began on 31 August 2020, enabling authors to present their work to a large audience; this edition also included a published version of those works in the ISPRS proceedings, and
- a 2021 edition taking place in July 2021 at the Nice Congress with the presentations of papers, for which a new submission and reviewing process will start in December 2020 with a deadline in early 2021.

For this 2020 edition, 1,850 papers from authors of more than 120 countries were submitted. All of these papers were reviewed by at least two, but on average three different reviewers. Out of these, 1,050 papers were finally published in the *ISPRS Annals* and *The International Archives of Photogrammetry, Remote Sensing, and Spatial Information Sciences*. More than 350 authors took the opportunity to present their work and results in a very successful and attractive three-day virtual event which was actually the first digital ISPRS event ever. Indeed, 2,000 people registered for this three-day virtual event of the 2020 edition. This event was not a mini-congress but was organized as a webinar with two parallel sessions to enable all authors to present their results. In addition to the papers, the authors also submitted oral pre-recorded videos that can permanently be viewed on a new ISPRS content portal. This video portal will be soon made freely accessible to all for education, training and capacity-building purposes, contributing towards the society's outreach mission.

Following the success of the 2020 edition, the ISPRS Council and the XXIV Congress organizers and sponsors hope to see everyone in Nice for the 2021 edition. Please note that the congress in Nice in July 2021 will be a fully hybrid event. Thus, those who cannot attend in person in Nice or who want to limit their travelling or their travel expenses will be able to take part remotely in all scientific sessions, in the exciting plenary talks, and in the Congress forum, discussing the future of our community. Remote participants will also have the possibility to present their work to the audience with their presentations being integrated seamlessly within the on-site sessions of the congress.

Nevertheless, we encourage as many XXIV Congress participants as possible to join us in Nice in person. Remember that Nice is nice and that nothing replaces a physical encounter to build, revive and deepen long-term professional and personal relations and friendships! Besides science, this is what ISPRS is all about!

▲ *The ISPRS XXIV Congress will be held in Nice from 4-10 July 2021.*


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