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The Revolution of Drone-carried Sensors

How UAVs Are Democratising Geospatial Information Gathering and Analysis

DRONES: A KEY LINK IN THE VALUE CHAIN

COMBINING HYDROGRAPHY AND UAV PHOTOGRAMMETRY

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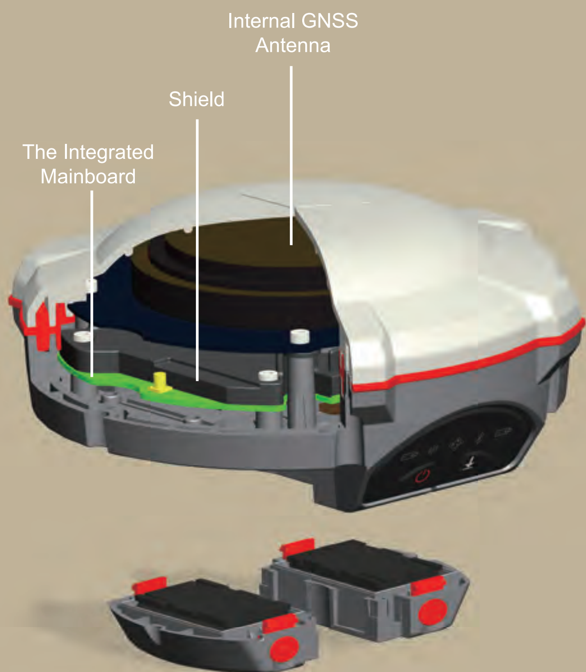
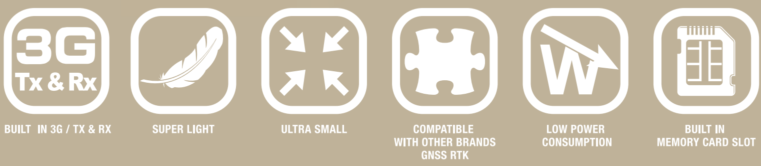
GNSS RECEIVER T300





THE NEXT LEVEL RTK

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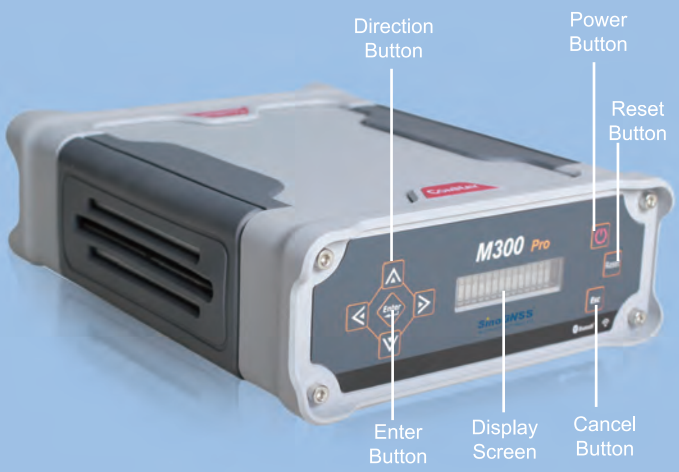

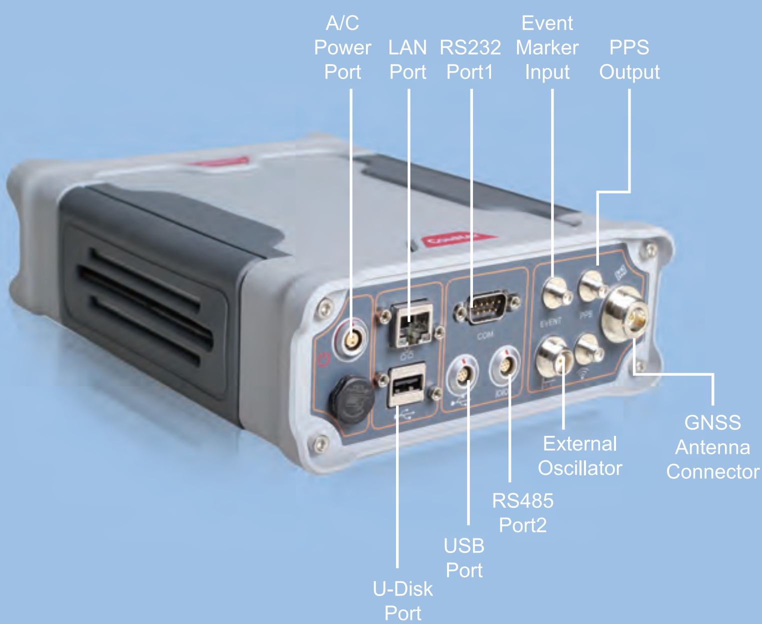

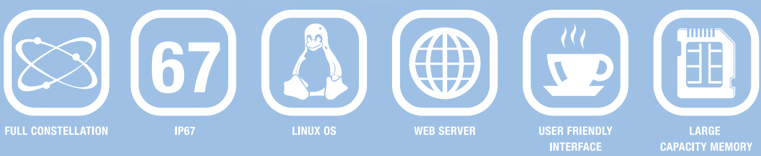

THE NEXT GENERATION CORS RECEIVER

This issue of GIM International has a special focus on unmanned aerial vehicles (UAVs), which have become essential tools for the surveying profession. Three separate articles zoom in on three different applications of UAV mapping. This edition also contains two extensive interviews that reflect the current transformation in the UAV business, where attention is shifting from the UAV itself to the sensors and the software too.

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Contemplation

While sitting in my backyard enjoying the first rays of spring sunshine, I saw a drone passing over the house, then moving on to the neighbours further down the street and finally disappearing out of sight behind the chimney stack. The passing drone made me think of the rapid pace of development we've seen over the past few years, the innumerable advantages of the deployment of drones – certainly in mapping and surveying, where they have fuelled the debate about fast and fit-for-purpose land administration – and not forgetting the development of the sensors: smaller, lighter, faster so that they can be mounted underneath the unmanned aerial vehicles (UAVs). The small aircraft above my head also brought to mind the discussion about privacy, which is never far away these days but is almost explosively present in UAV-related policymaking. Many countries have recently developed or adjusted their set of rules. In the UK, for instance, one is not allowed to fly a drone within 150 metres of a built-up area nor within 50 metres of a person, vessel, vehicle or structure not under the control of the pilot. In the USA, as in various other countries, there must always be line of sight and the drone must be close enough to be commanded. It may sound very logical, but drones are always required to give way to professional aircraft. Ensuring that the rulemaking keeps pace with technological development is even more of a challenge, I assume. These sets of rules are still 'work in progress', which means that legislation will continue to be a hot topic at every major conference, such as AUVSI Exponential in Dallas and Commercial UAV in Brussels and Las Vegas. Safety is another big issue linked to the use of drones, whether for fun or for professional purposes. In the last few years there have been dozens of near misses between aircraft and drones, not only at Amsterdam Airport Schiphol here in The Netherlands but also around Heathrow Airport in London, UK. Whereas the drone that flew over my head on that sunny Sunday afternoon was probably a recreational one, the fields of professional application for small unmanned aircraft are increasing quickly. UAVs are now used in defence, surveying and mapping, mining and precision agriculture, but also for law enforcement and search & rescue as well as for plant inspection and much, much more. For surveying companies, UAVs might be the most revolutionary vehicles ever as they can now make surveys possible in places they hardly dared to dream of. For the business as a whole, UAVs could be the vehicles that carry experience and technology from the worlds of mapping and surveying – like photogrammetry, remote sensing and most notably Lidar – to all the other fields. This edition of *GIM International* includes lots of editorial focus on the deployment of unmanned aerial systems (UASs), such as in railway inspection (see, for instance, the feature article by Jakub Karas on 'UAS Photogrammetry and Railway Mapping' on page 27). But this issue also offers a brief look into the future in our regular '5 Questions to…' section, in which this month Pix4D's Christoph Strecha provides the answers (see page 13). I hope you enjoy reading *GIM International*, whether at your desk, on a plane or even in your backyard. From experience, I can tell you that a spot of contemplation in the early spring sunshine is inspirational!

▲ *Durk Haarsma, publishing director*

UAS Applications Are Ubiquitous

Unmanned aerial systems (UASs) include imaging systems and/or airborne Lidar systems on an ever-increasing number of variously sized, remotely piloted fixed-wing or multi-propeller systems – the latter being able to hover and take-off vertically – as well as hybrid systems. In *GIM International* and other surveying and mapping literature, there have been many articles describing the use of UASs, new developments and precautions that need to be taken to achieve satisfactory results. In many countries, small UAS operations must satisfy specific regulatory conditions. These limit the airspace for UASs to below 400 feet (approximately 120 metres) and only allow them to operate while the UAS is within the operator's visual line of sight (VLOS). The operator typically must also have the appropriate UAS certificate to apply for operations above 400ft or beyond visual line of sight (BVLOS). The limitation of the maximum flying height to 400ft above the take-off location restricts the ground sampling distance (GSD) of images for geomatics applications to approximately 5cm. This is an advantage for many applications, however, since the purpose of many UAS flights is to monitor objects, vegetation and other features at close range.

Due to limited battery capacity, the area that can be covered in a single flight is typically of the order of 1 square kilometre. For larger areas UAS use may be uneconomic for surveying and mapping tasks in comparison to manned aerial photography. Research has shown that adding a solar capability to the UAS can increase flight time significantly, to up to four hours for a single flight.

UAS technologies have not been specifically designed for the geomatics fields, leading to many new civilian and commercial applications of UASs. Some typical applications described in the literature are: storm/hurricane monitoring; parcel delivery; emergency services; wildfire monitoring; wildlife protection; a range of agriculture tasks; asset and infrastructure inspections, especially in remote areas; security; exploration; environmental assessment; mass media; real estate; transport and traffic monitoring; international peacekeeping and monitoring vulnerable populations for human rights abuses; the visual arts; and many more. Some researchers claim that up to 30,000 civilian and commercial UASs could be flying in the skies over US cities within the next decade.

Many UAS applications described above are limited by the current civil aviation conditions. It could be argued that, without sophisticated collision avoidance, UAS development is still at a primitive stage. Research is being undertaken into collision avoidance systems. This

▲ *John Trinder*

▲ *Yincai Zhou*

should improve the applications of UASs and could allow them to fly within civilian airspace as well as avoid collisions with objects outside of civilian airspace, particularly when multiple UASs are being used. Furthermore, NASA in the USA is researching prototype technologies for a UAS Traffic Management (UTM) system, which includes airspace design, dynamic definition of boundaries for safe operations of UASs, congestion management and terrain avoidance that could lead to integration of airspace requirements for safe, efficient, low-altitude operations.

How much does positional accuracy matter?

In many applications of UASs, the most important information is the spectral characteristics of the terrain cover derived by multispectral or thermal cameras. In this case, since the exterior orientation parameters derived from the global navigation satellite system (GNSS) receivers and the inertial measurement unit (IMU) are usually inadequate to determine reliable positioning, mean square error (RMSE). Rich ground surface texture enables more auto-tie points and hence a higher-accuracy point cloud. Lower accuracies are likely to be achieved if the overlaps are reduced.

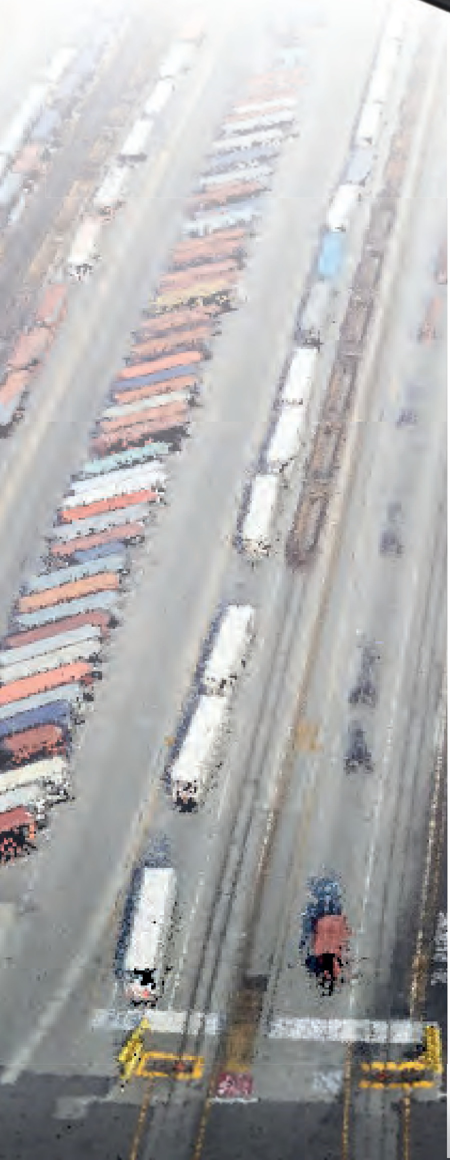
UAS Lidar

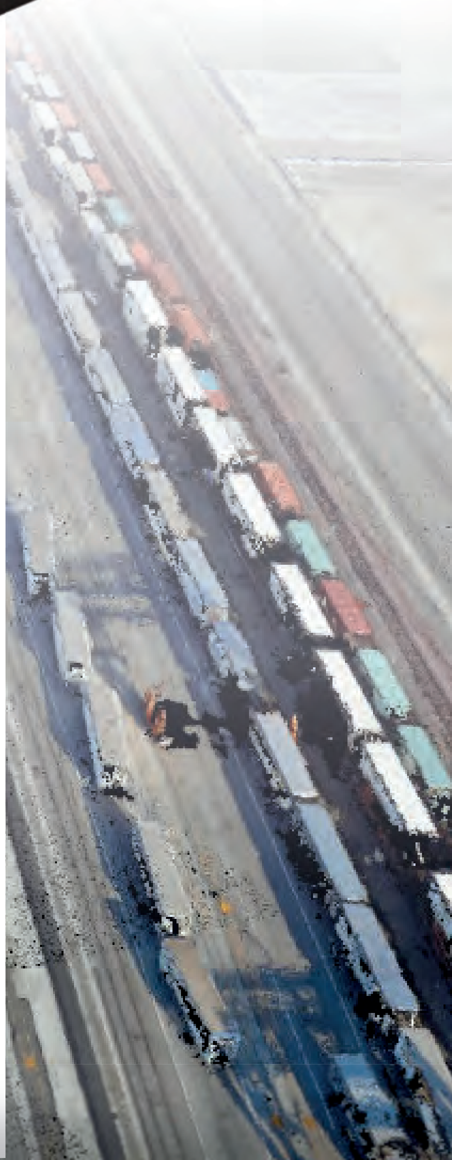
UAS Lidar mapping is available in the geospatial market but it is not as mature as UAS photogrammetry due to the high price tag for high-accuracy, low-weight Lidar scanners, as well as the need for a precise GNSS/IMU. UASLlidar mapping does not require large overlapped scans, and a single flight can cover a much larger area than UAS photogrammetry. However, the flight time is usually much shorter due to the heavy payload (typically 2kg) compared with a compact camera (typically 200g). UAS Lidar mapping usually uses onboard RTK GNSS for heading and IMU for pitch and roll. Heading accuracy still needs to be improved to achieve comparable point cloud accuracy at the same flight height as UAS photography.

30,000 DRONES COULD BE FLYING ABOVE US CITIES WITHIN THE NEXT DECADE

commercial bundle solutions using ground control points or transformations based on auto-tie points are required.
High positional accuracy for mapping applications is a product of the entire UAS system including the sensors, e.g. spectral cameras and airborne Lidar, exterior orientation parameters derived from the GNSS receivers and the IMU, operations and software, flight planning especially in difficult terrain or dense vegetation cover, as well as accurately surveyed ground control points. The cameras are usually calibrated by in-flight procedures based on an adequate number of auto-tie points or ground control points. If the images are acquired with overlaps of typically 80% along the flight direction and at least 70% between flights, the accuracy of densified point clouds derived from UAS images will be of the order of 1 to 1.5 GSD in position and 1.5 to 2 GSD for heights measured as a root

Thanks to the availability of software for processing UAS images, it is possible for individuals without any knowledge of photogrammetric processes such as bundle adjustment to acquire and process UAS images without appreciating the capabilities of the software and/or their shortcomings. These can include aspects of flight planning, flight speed, imaging angle, imaging time of the day and control point distribution in the surveyed area. Image quality is also a factor to consider for mapping accuracy. Geospatial professionals have the know-how to achieve the proposed accuracy by considering flight parameters, camera set-up, image quality, terrain surface and control point distribution, coordinate systems, software processing set-up and parameter configurations. Therefore, it is strongly advisable to engage a qualified professional for the acquisition and processing of the UAS images.





ColourCloud Processing Hosted on Google Cloud Platform

NCTech, a developer of reality imaging systems, has announced that its ColourCloud software is being hosted on Google Cloud Platform. At the Google Cloud Next '17 conference, Intel confirmed that the next-generation Intel Xeon processor family (also known as Skylake) is now available on Google Cloud Platform. Google Cloud Platform is the first to offer cloud services based on Skylake. The Intel Xeon processor supports Intel AVX-512 instructions to run compute-intensive workloads more efficiently, such as high-performance computing, video processing and data analytics. This development provides powerful support for the capture and processing of 3D imaging. With ColourCloud now hosted on Google Cloud Platform, NCTech is able to provide a secure, end-to-end capture, process and delivery workflow for its customers.

▸ **http://bit.ly/2n5gCda**

ColourCloud Software.

Geospatial Data for UK's Smart City Demonstrator Project

The city of Manchester.

Ordnance Survey (OS) is currently in Manchester, UK, collecting geospatial data to a similar level that it did across all the 2012 Olympic sites. That project contributed to the successful planning and smooth delivery of a safe and enjoyable Summer Games. The activity OS is undertaking in the Corridor Manchester area is part of CityVerve, the UK's Smart City demonstrator project. OS is collecting this data to stimulate innovation that it and project partners believe will lead to better services for residents, visitors and business. OS, whose digital database of Great Britain contains more than 500 million unique geographic features presenting the most detailed, location-data-rich picture of the country, is challenging itself through CityVerve to see what extra information can be found in the real world that will be of benefit to the nation.

▸ **http://bit.ly/2n5mWS6**

Topcon and Bentley Bundle Reality Modelling Software with UAS

Topcon Positioning Group has introduced Topcon ContextCapture, powered by Bentley Systems, a reality modelling software solution that will be offered with Topcon unmanned aerial systems (UASs). The system is designed for mapping, construction and surveying professionals. It enables them to quickly turn simple photographs and/or point cloud data into true-to-life, highly detailed 3D models for use throughout a project life cycle. The offering will include Topcon ContextCapture Standard and Topcon ContextCapture Advanced, said Charles Rihner, vice president of the Topcon GeoPositioning Solutions Group. The standard package will be bundled with Falcon 8 and Sirius Basic/Pro and allows operators to process data from these UASs into textured 3D reality meshes, point clouds and orthophotos. ContextCapture Advanced allows users to process data from any UAS. It also includes ContextCapture Editor, which enables operators to take advantage of all project data by integrating reality meshes and point clouds into infrastructure workflows. The result is access to a wide variety of reality modelling tools to help increase productivity.

▸ **http://bit.ly/2mnwJzs**

Topcon Falcon 8.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Survey-grade LiDAR performance with size, weight, and cost factor that makes deployment on sUAVs practical and economical for commercial applications!
Key Features:
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Aeryon Labs Successfully Completes First Approved BVLOS Flight Test

Aeryon Labs, a Canada-based manufacturer of unmanned aerial systems (UASs), has announced that the Aeryon Sky Ranger UAS has successfully completed the first Beyond Visual Line of Sight (BVLOS) flight in Canada. The SkyRanger was chosen by Ventus Geospatial and Canadian Unmanned as the vertical take-off and landing (VTOL) sUAS flown for BVLOS testing and evaluation throughout the trials at the Foremost UAS Range. These flight trials, which are among just a handful of BVLOS trials worldwide, are a milestone for aviation as they help to establish safe operational procedures and protocols for operating UASs of under 25kg beyond the line of sight. This inaugural flight creates the foundation for how sUAS operators can legally and safely fly BVLOS within Canada and across the globe.

http://bit.ly/2mnvoro

Aeryon Sky Ranger.

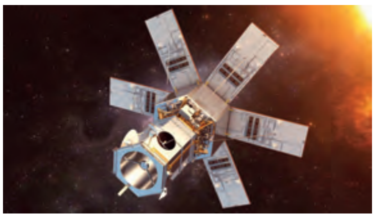
Esri and Harris to Modernise Data Production from New Image Sources

Esri, the global leader in spatial analytics, has signed an enterprise agreement with Harris Corporation. In addition, Harris Corporation has become an Esri Platinum Tier partner. The agreement and partnership afford the corporation access to all Esri software and top-level benefits of the Esri Partner Network throughout the Harris Space and Intelligence Systems segment. This commitment to collaboration will help programmes across multiple security domains meet the expected surge of commercial imagery from small satellites, unmanned aerial system platforms and open data sources. Esri and Harris Corporation are embarking on a broad strategic relationship to develop geospatial intelligence data production apps and tools for federal agencies. The partnership will significantly advance operational efficiency by automating the analysis of data and imagery for organisations that are increasingly relying on data integration in maps and imagery analytics.

http://bit.ly/2lWUsKx

Display Room, Harris Geospatial.

MDA Acquires Earth Observation Giant DigitalGlobe



WorldView-4 satellite.

MacDonald, Dettwiler and Associates (MDA), a global communications and information company providing technology solutions to commercial and government organisations worldwide, and DigitalGlobe, a global leader in Earth imagery and information about the changing planet, have entered into a definitive merger agreement. The transaction values DigitalGlobe at an equity value of approximately USD2.4 billion and an enterprise value of USD3.6 billion. The combination will bring together complementary space-related capabilities, creating a stronger company with the ability to provide complete, end-to-end space systems, Earth imagery and geospatial solutions and hence positioned to capture growth in the US, Canadian and global Earth observation and geospatial services markets. DigitalGlobe operates the WorldView series of Earth observation satellites, including the recently launched WorldView 4 observatory. Together, the combination will leverage a full suite of space-related capabilities, including communications and Earth observation satellites and robotics, ground stations, integrated electro-optical and radar imagery, and advanced data analytics. Additionally, the combined company will lead in cloud-based information services that allow commercial and government customers worldwide to better understand activity across the changing planet.

http://bit.ly/2njx75W

Sentinel-2B Satellite Launched into Orbit

Sentinel-2 satellite.

The ESA-developed Sentinel-2B satellite has been launched. This doubles the coverage of high-resolution optical imaging in the Sentinel-2 mission for the European Union Copernicus environmental monitoring system. The 1.1 tonne satellite was carried into orbit on a Vega rocket from Europe's Spaceport in Kourou, French Guiana, at 01:49 GMT on 7 March (02:49 CET; 22:49 local time on 6 March). With this launch ESA is taking another step toward advancing the Copernicus programme, which is the most sophisticated Earth observation system in the world. Moreover, with Sentinel-5P and Sentinel-3B, the European Space Agency is planning to add two more satellites to the constellation in the next months, according to ESA director general Jan Wörner. The optical imaging Sentinel-2 mission is based on a constellation of two identical satellites: Sentinel-2A, which was launched in June 2015, and Sentinel-2B. Although launched separately, the satellites are placed in the same orbit, flying 180° apart. Every five days, the satellites jointly cover all land surfaces, large islands and inland and coastal waters between latitudes 84°S and 84°N, optimising global coverage and data delivery.

▸ **http://bit.ly/2noXmVt**

SI Imaging Services Announces Reseller Agreement with Land Info

SI Imaging Services (SIIS) has reached a major reseller agreement with Land info Worldwide Mapping (Land Info). The contract, effective from 1 January 2017, makes Land Info an authorised reseller of KOMPSAT data. With this agreement, Land Info will expand its offering of value-added feature extraction and classification to include the use of KOMPSAT imagery. Commenting on the new agreement, Nick Hubing, president of Land Info, stated that imagery from the constellation of KOMPSAT-2, KOMPSAT-3, KOMPSAT-3A and KOMPSAT-5 is an important addition to their online search tool, so customers have access to the broadest range of archive imagery. SIIS support for worldwide sales streamlines Land Info's ability to support transnational projects.

▸ **http://bit.ly/2mRQt05**

KOMPSAT-5.

New Partnership for Easy Access to Fresh Earth Observation Imagery

Airbus Defence and Space satellite imagery.

Airbus Defence and Space has closed a partnership agreement with Bird.i, a global platform developed for accessing the world's best satellite, airborne and UAV imagery. The objective of the partnership is to allow real-time online visualisation of Airbus Defence and Space's freshest Pléiades and SPOT satellite images, and support the development of new applications and services across a wide range of related analytics markets. Set up in 2016, Bird.i team has developed a plug-and-play application programming interface (API) for mapping and location-based applications for a variety of needs, ranging from professional to leisure needs. As part of this agreement, Bird.i will have online access to One Atlas, the world's freshest satellite image library developed by Airbus.

▸ **http://bit.ly/2nAEUbC**

The Netherlands Invests in Satellite Data for Precision Farming

Satellite data boosts precision farming.

The Dutch government is freeing up EUR1.4 million for the purchase of satellite data to improve the sustainability and efficiency of farming. Among other things, the data contains detailed information about the soil, the atmosphere and crop development. Specialised companies can analyse the data to provide farmers with targeted advice on irrigation, fertilisation and crop-spraying activities. The satellite data will be made available online as open data, allowing everyone to have free access to it. The Dutch agricultural and horticultural sector enjoys a very strong international reputation, and the government is keen to support this leading position by investing in innovation. Satellite data enables farmers to monitor crop progress very closely and to take corrective action precisely where it is needed, thus resulting in greater efficiency and sustainability.

▸ **http://bit.ly/2nHZuHd**

5 Questions to... Christoph Strecha (Pix4D)

Dr Christoph Strecha is the CEO and founder of Pix4D, a Swiss company which develops and markets software for production of survey-grade 3D models and orthomosaics from images. In this Q&A with Strecha, *GIM International* gains an update on the current status of mapping using unmanned aerial vehicles (UAVs) as well as a glimpse of where the Swiss company is heading.

Your company makes software solutions for UAV-based mapping, purely from images. Are there no plans to expand to Lidar?

Lidar is very interesting in combination with photogrammetry. Especially terrestrial Lidar and UAV- or drone-based photogrammetry point clouds create good synergy. Exciting partnerships and software solutions are to come for Pix4D. For us, however, drone-based Lidar is less interesting. It consumes power (active 3D) and is heavy in comparison to cameras, reducing the drone's flight time or requiring the drone to be much bigger. Therefore, I don't think drone-based Lidar will become mainstream in the next few years.

UAV mapping has been an ongoing trend since heavy and expensive sensors are no longer required to produce high-quality data. Which major developments do you foresee for the coming years?

After the hype surrounding the drones themselves, we will now see a heavier focus on the payloads. Sequoia (multispectral camera) is a nice example of a more dedicated, application-specific payload. This trend will continue. The drone is, as it should be, the 'tripod that carries the measurement device'. Drones have helped spur the adoption and awareness of the power of photogrammetry. Often, though, they are not the optimal way to capture data. We think that the hype will settle and people will realise that it's not the drone that is important, but the data – which in some cases can come also from a crane camera. I also think we will see a breakthrough of drone applications when the drone itself becomes smaller and less dangerous. This will, of course, also allow easier adaptation in terms of flight regulations.

Your main product, Pix4Dmapper, focuses on processing images from small-format cameras that are used in UAS photogrammetry, among other things. How will your product portfolio evolve over the next five years?

We started to verticalise our products last year, offering more specific solutions for several distinct markets such as professional surveying, agriculture, construction and real estate. Pix4D will continue in this direction to increasingly understand specific customer segments and develop the best products for them. The integration of local desktop processing for fast results and integrated visualisation in the cloud, which allows collaborative viewing, communication and review work, is important to meet customer segments' specific needs.

What's your explanation for the great success of UAS photogrammetry?

The fun of consumer drones! Professionals that flew them for fun quickly realised that these consumer drones carrying a camera could be very useful in their professional life. They became interested and saw the professional drones, such as the eBee, offered even greater potential.

The more data sensors produce, the more important it becomes to derive information automatically. What is your impression of today's status of automated scene analysis, and where is it heading?

We cannot begin to imagine how much data is being collected today that nobody has time to look at. This trend will be enormously magnified, not only in drone mapping. We won't have the manpower to extract information from all the data and results being produced today. Automated solutions will solve this dilemma. Instead of getting a 3D point cloud from images, we will see more and more automatic semantic extraction. It's not the 3D point cloud that matters, but where the windows are, how many there are, and what has changed on the building surface since last year's survey. For specific applications we're already seeing this happening, and will continue to do so. Pix4D has the largest research and development team out of all the photogrammetry software companies, which I believe gives us an advantage to lead, also in the domain of semantic scene interpretations.

More information
www.pix4d.com

GIM INTERNATIONAL INTERVIEWS 3D ROBOTICS

The **Revolution** of **Drone-carried Sensors**

The world of professional unmanned aerial vehicles (UAVs or 'drones') is changing. It is a matter of 'survival of the fittest' in terms of the hardware aspect: UAV manufacturers. The interest is now visibly shifting towards payloads and software to capture, visualise and process the data; UAVs are the apparatus, but it's the sensors and software that really count. *GIM International* decided to touch base with a company that serves as a good example of the current transformation, and spoke to Chris Anderson, CEO, and Daniel McKinnon, vice president, from 3D Robotics.

3D Robotics was founded back in 2009. What made you decide to enter the UAV business?

Chris: It was back in 2007 that I built my first drone at home with my kids. Not much later I created an online community, DIY Drones, where I met Jordi Muñoz, a 19-year-old college dropout and electronics wunderkind from Mexico, who demonstrated his talents by creating a fully functioning autopilot using circuitry lifted from a Nintendo Wii remote. In 2009 we set up our own company, 3D Robotics. We chose this name as it alludes to

Daniel McKinnon, vice president.

Chris Anderson, CEO.

the third axis – up – where consumer robots hadn't yet been. In late 2012 I quit my job as editor-in-chief of *Wired* to focus full-time on the drone business.

At that time, did you have any idea of the endless possibilities for UAVs, such as in surveying and mapping?

Chris: Yes and no. I certainly knew that there would be many applications for UAVs; as a matter of fact, I was more interested in the applications than I was in the drones themselves. When I first made drones in 2007, they were called 'geocrawlers' – like a web crawler but for the Earth, to measure the world. My vision has always been that there is an opportunity below the satellites, below manned aircraft, to do with the physical world what Google did for the web. So I was interested in putting sensors in the sky, and drones were just the best way to do it. I didn't actually know what the specific applications would be, but I guessed they would probably be linked with agriculture, wildlife conservation, the environment, etc. I didn't think very hard about it; I just assumed that experts in those domains would show me how to use the sensors in the sky and that I would learn from them – and that in fact turned out to be true.

You're moving away from manufacturing consumer drones. Why did you decide a new strategy was necessary?

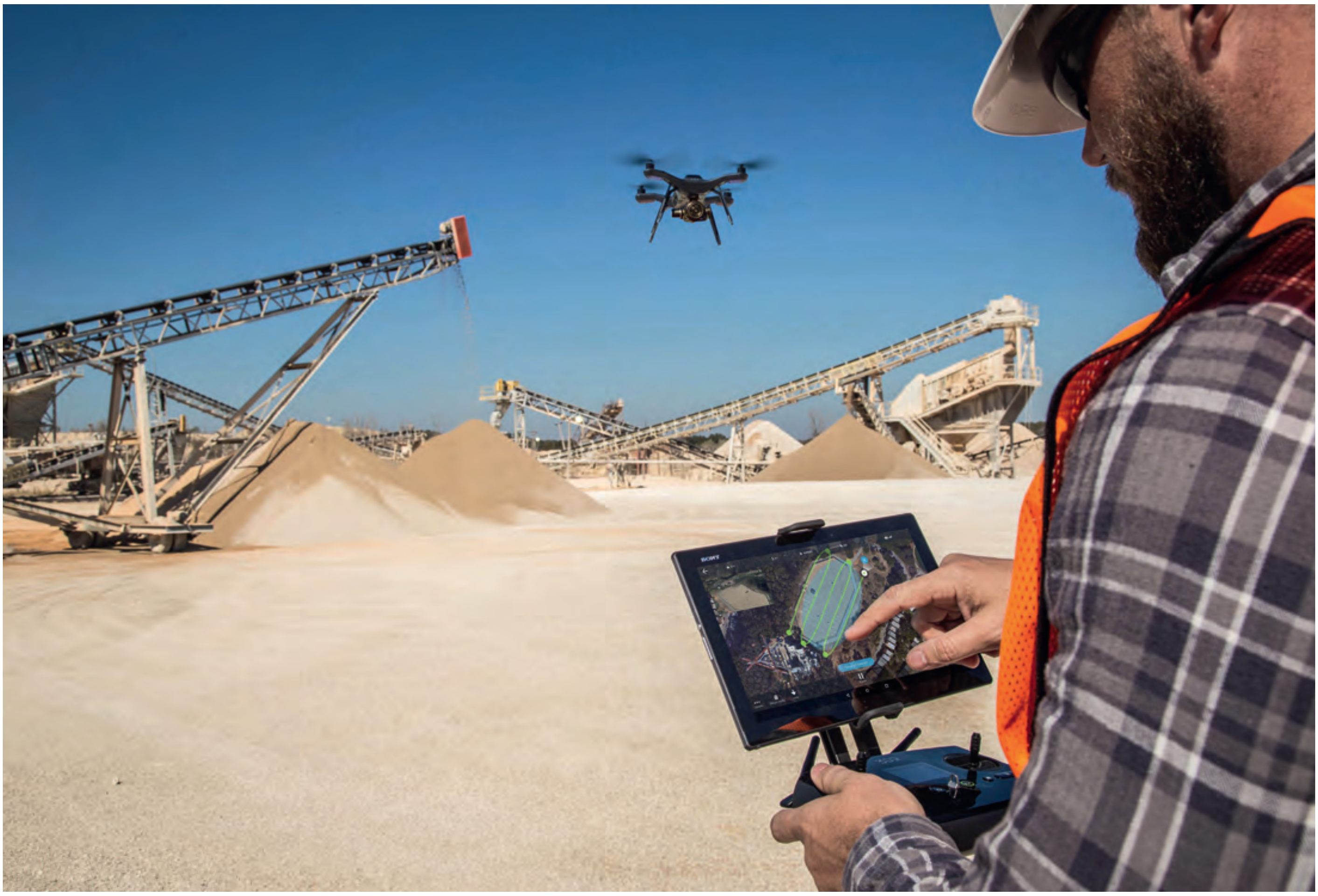
Chris: That requires some explanation. The industry is actually going through three phases and they were predictable right from the very beginning, in the late 2000s. We knew there would first be the technology phase: the software, the autopilots, the sensors – the core 'brains' of a drone. We did very well in that phase. We knew the next phase would be the consumer phase, a 'toy' for want of a better word, thanks to the exemptions making recreational drone use legal – unlike commercial use. So the only real path to market would be via the consumer. We also knew that the endpoint in terms of our interest was the commercial use, i.e. less about the drone, more about the data. So this progression from technology to toy to tool was predictable from the very start. Unfortunately there was no way to just hop from technology to tool; we had to go through the toy phase, because that's where the ease of use, the design and the overall package benefited from the demands of consumer acceptance. This phenomenon, the 'consumerisation of the enterprise', has held true ever since the iPhone. Rather than making complicated tools for professionals and easy tools for consumers, everybody wants easy tools – an iPhone equivalent. Whether a consumer is using a drone to film video or a construction worker is using the drone to scan, neither of them care about the technology or want to be trained as pilots, they just want a result.

However, the consumer phase is extremely expensive. You have to deal with retail, distribution, volume, customer support and so on. The consumer electronics market is tough at the best of times, and we happened to be competing with one of the best companies in the world: DJI. DJI represented a new era of Chinese companies that moved really fast, had extraordinary scale, great software, hardware, distribution, marketing…they really did everything right. It became clear very quickly that they could operate at a price point that we could not. We were fortunate to see the writing on the wall relatively early, so we actually decided to move out of the consumer hardware back in 2015 to focus entirely on the commercial applications. Today we're seeing other companies, such as GoPro and Parrot, feeling exactly the same kind of pain. Now, we not only feel somewhat lucky to have been the first to discover how tough the market was and be the first to get out, but also that our plan had always been to get commercial as quickly as possible. The silver lining in the consumer boom is that it forced the regulators to accelerate making commercial use legal.

THE SILVER LINING IN THE CONSUMER BOOM IS THAT IT FORCED THE REGULATORS TO ACCELERATE MAKING COMMERCIAL USE OF DRONES LEGAL

Instead of UAVs, you're now focusing on the Site Scan software for capturing and analysing aerial data. How does Site Scan work exactly?

Chris: Site Scan is a three-part product: the 'box' (the drone, camera and batteries), the iPad app and the cloud service, in conjunction with Autodesk. You simply push the button on your iPad and the drone takes off, takes the necessary pictures with a very good camera – the Sony UMC-R10C – with all the right settings and then transfers those images to the cloud where they are converted



into 2D orthophotos and 3D models using the Autodesk engine. You then have data that seamlessly integrates with the Autodesk software. The drone part is now the least interesting – it works great and is fully autonomous, but that's true for all drones nowadays. The 'secret sauce' is the software – the ability to not only capture the right data but then to overlay it with CAD data from the Autodesk tools, to be able to do measurements, to be able to visualise it in new ways in the conventional tools in the AEC (*Architecture, Engineering and Construction, Ed.*) market, like BIM360, Civil3D, Revit and even AutoCAD. As part of the Autodesk portfolio, our job is to basically be the 'capture' part of people's 'reality capture' strategy.

You claim that the georeferencing tool included in Site Scan Manager enables orthomosaics and digital elevation models to be generated that are accurate to their theoretical limit. Is this true?

Daniel: Typically, the generation of an orthomosaic will lose between one and three times the accuracy of the ground sampling distance (GSD), so the theoretical limit of the accuracy of an orthomosaic is one times its ground sampling distance. In UAV-based photogrammetry, the GSD of the camera – let's say it's 1cm per pixel – gets diminished once you create the mosaic because of the computer vision used to stitch the images together. In that particular case, we ended up with about 2cm per pixel. So for a 10-acre site with five ground control points, we would achieve close to the theoretical maximum accuracy.

In November 2016 you announced the launch of building information modelling (BIM) capabilities within Site Scan. To what extent is this a game changer for the construction industry?

Daniel: The capture part of reality capture is only as good as what you can compare it with: the 'as built' compared with 'as designed'. The 'as designed' is a bunch of CAD files that designers and engineers use to prescribe the construction of a building or a piece of infrastructure. The 'as built' is what we measure, closing the loop of the design-build cycle. So, for example, with Site Scan you can make sure concrete is laid down properly, eliminating things like having to jackhammer overpours. So yes, this truly is a game changer for the industry. Whereas previously you would only catch an error several steps beyond it, you can now do it in near real time.

Chris: The digitisation of the built world, of the construction industry, is only half completed. We design things digitally, but once they get built they become analogue. So we need to be able to essentially 'redigitise' the physical world and then merge it with the design to see if anything has changed. The promise of BIM, with a fully digital workflow, is that modelling buildings not only enables you to catch errors during construction but also allows you to feed any changes made in the real world back into the digital model to keep it up to date.

How will this stronger focus on construction affect your commitment to the mapping and surveying industry?

Chris: Those two industries are on a continuum, and they're moving towards each other. The GIS world is the world of latitude and longitude –

absolute frames of reference in the real world. Meanwhile, the construction world has typically been one of CAD, which is all relative dimensions. Traditionally, the Autodesks of the world work in coordinate systems that are relative to a building site, whereas the GIS companies often don't get into that sort of building-level granularity. What we're seeing now is two worlds starting to converge: the AEC world is starting to move outwards, from just the building to the building on the site and the site in the city – all part of the broader urban infrastructure. Meanwhile, as resolution continues to increase, the GIS world is starting to move into the actual building level. The building site is our starting point, because there's a clear and present need in the construction industry, but as we build these tools we're finding ourselves extending out into GIS more and more. So we started with Autodesk, but we're now working very closely with Esri on the GIS side and I think will we see some commonalities, some harmonisation between these two industries on things like file formats, coordinate systems, databases and so on. We feel we have the potential to be a bridge between those two industries.

So 3D Robotics manufactures UAVs and software, but how about the payload? Who supplies the systems?

Chris: We manufacture the gimbal and the interfaces and all the other bits necessary to make the Sony R10C camera appropriate for use on a professional drone. That's all we do right now on the hardware side, and over time the entire industry is becoming somehow agnostic about the drone. Companies like DJI and Yuneec make amazing drones. It's like with smartphones; you can buy a Samsung or LG or HTC or whatever – their phones are so sophisticated that you can assume the hardware is good enough. We're very close to that point with drones as well.

Will you be focusing on any other mapping technologies, such as Lidar?

Chris: Lidar and other laser ranging techniques are very hot right now. In the same way we are agnostic about the drones, we want to be agnostic about the sensors we use. Right now we use cameras just for photogrammetry, but the same tools we use – the Autodesk Recap engine and others – can actually take input from Lidar too, so you can combine point clouds from Lidar with point clouds from photogrammetry. Imagine a building – for some aspects it is better to survey it from the ground. Anything that involves looking up, behind obstacles or inside is better done with Lidar. Other things, especially things that are higher off the ground, are better done with a drone, with photogrammetry. The ability to combine aerial photogrammetry, ground-based Lidar and interior photogrammetry into one holistic point cloud is the workflow we're working on right now with Autodesk.

Our recent readers' survey indicated a rising demand for accurate and easy-to-use point cloud processing software for UAVs. How are you capitalising on this opportunity?

Chris: There are three elements in the point cloud processing software. One of them is the acquisition of the data in the first place, which is done with our mobile app. The second is the creation of the point cloud, which is done with the Autodesk Recap Engine. The third is the tool to visualise it, to combine it with other data, to annotate it, et cetera, that's what we do with our web tools. You're absolutely right when you say that today's tools are still a little fragmented and are often hard to use. So we see a huge opportunity to simplify the workflow and make it easier to capture, process and visualise point clouds.

EVERYBODY WILL SOON HAVE ACCESS TO THE TOOLS THAT ONLY SATELLITE OWNERS HAD JUST A FEW YEARS AGO

Is there anything else you want to share about the surveying and mapping industry and the applications of UAVs in general?

Chris: My message is simple: the sky is empty! It's really amazing that there is still an opportunity that big and that untapped today. The industry has done extraordinary things with satellites, but two-thirds of the planet is covered by cloud at all times. Aeroplanes are useful but they are expensive and not available everywhere. With drones it is now possible to put a sensor in the sky pretty much anywhere, anytime, for almost no cost. I think this is as important as the origins of the satellite industry in the first place. Not only are drone-carried sensors cheaper, available nearly anywhere and anytime and able to capture data at higher resolution due to their lower altitude, but they are also connected to the internet. So these sensors benefit from cloud data processing, providing insight in near real time. In the same way that the internet democratised telecoms, I think drones will democratise geospatial information gathering and analysis. Everybody will soon have access to the tools that only satellite owners had just a few years ago. ◂

CHRIS ANDERSON

Chris Anderson is CEO of 3D Robotics, founder and chairman of the Linux Foundation's Dronecode Project, and founder of the DIY Drones and DIY Robocars communities, including the ArduPilot autopilot project. From 2001 to 2012 he was the editor-in-chief of *Wired* magazine. Before *Wired* he spent seven years with *The Economist* in London, Hong Kong and New York. Anderson is the author of the *New York Times* best-selling books *The Long Tail* and *Free* as well as, most recently, *Makers: The New Industrial Revolution.* He was listed among *Time* magazine's 100 most influential people in the world in 2007 and in its Tech 40 as one of the most influential minds in technology in 2013, as well as one of *Foreign Policy* magazine's Top 100 Global Thinkers in 2013. Chris Anderson has a background in science, starting with studying computational physics and doing research at Los Alamos and culminating in six years at the two leading scientific journals, *Nature* and *Science*.

DANIEL MCKINNON

Daniel McKinnon is vice president of product at 3D Robotics. He has worked closely with the Autodesk ReCap team to build Site Scan, an intuitive application for autonomous drone scans that seamlessly integrates with the Autodesk software ecosystem. Site Scan enables Autodesk customers to generate aerial imagery, orthophotos, point clouds or meshes for infrastructure planning, construction monitoring and myriad other uses. McKinnon completed a bachelor's degree in physics and doctorate in chemical engineering before co-founding Agribotix, an agricultural survey company, after being conscripted by the Denver Zoo to develop a drone for wildlife observation and capture. At Agribotix, he worked extensively with growers and agronomists to develop both a front-end data collection workflow and a back-end data processing solution that quickly and easily gets valuable actionable intelligence into their hands. These efforts have resulted in the establishment of several concrete value propositions for drones in agriculture as well as numerous lessons for what does and doesn't work in the field.

CREATING A 3D MODEL FOR VOLUME CALCULATION WITH BOAT AND UAV

Combining **Hydrography** and **UAV Photogrammetry**

What is the best way to generate a high-precision 3D model to estimate the storage capacity of a lake that is surrounded by mountains? Rapid weather changes, low clouds and steep mountainsides demand a sensible approach with the right equipment. This article provides insights into the surveying process of a lake mapping project including the methods used to create a 3D model for the generation of a precise map with elevation lines.

Figure 1, View of the Klöntalersee lake with the Glärnisch mountain massif on the left.

Situated at 848 metres above sea level in the Swiss Alps, created by an ancient rockslide and flanked by the 2,900m-high Glärnisch mountain massif (Figure 1), the Klöntalersee lake is a stunning attraction for tourists and artists alike due its ravishing beauty. But poets and painters are not the only ones to have recognised the potential of the 3.3km^2 lake, which is fed by the surrounding mountain brooks like the Klön. In 1908 a dam was constructed on the eastern side of the Klöntalersee, between Rhodannberg and Sackberg, to generate electricity for homes and businesses in the surrounding area. Thanks to the bulk earth dam, which today is 220 metres long and 21.5 metres high, the lake can hold approximately 39.8 million cubic metres of water, which can be used to generate electricity during times of demand peaks or fluctuations.

In an approach combining hydrography and photogrammetry, the IngenieurTeam GEO crew planned to survey the area using their sounding boat *Surveyor*, the industrial unmanned aerial vehicle (UAV) Aibot X6 (Figure 2) as well as positioning technology from Leica Geosystems to generate a 3D model for accurate and centimetre-precision calculation and simulation of the actual holding capacity.

▲ *Figure 2, Aibot UAV and surveying vessel* Surveyor *at the Klöntalersee.*

MULTIBEAM ECHOSOUNDER

After all the preparatory measures, approval processes and planning steps had been completed, the experts travelled with their sonar-equipped vessel *Surveyor* to the Klöntalersee to map the lake's soiling situation at a regular water gauge. With 172 planned recording lines, the six-metre-long vessel set sail to create a detailed picture of the lake's soil using its Teledyne Reson SeaBat 8101 multibeam echosounder. The fathometer emits acoustic signals at an angle of 150 degrees and calculates the depth of the water by measuring the elapsed time of the echo. With 101 beams per ping at a frequency of 30 pings per second, the hydrographs receive high-precision data of the bed with a graticule of 3,030 single points per second. With an overlap of one third of every measuring track, the experts achieved an accuracy of better than ten centimetres during their measurements. But before gathering the data, the measuring system had to be calibrated precisely in order to avoid disturbance factors and to correctly determine the results.

ADJUSTING THE SENSORS

That entailed adjusting the sensor technology before every deployment to subtract both linear movements of the vessel as well as rotation around its axles to impede any errors. A further step for the hydrographers to obtain a clear and detailed view of the lake bottom was to factor the water's sound velocity into the calculation. The sound velocity changes depending on temperature and suspended particles and becomes especially important in lentic water.

After the boat had been launched and calibrated, the crew put out to sea on a 2.5-hour initial cruise to get a first impression of the lake's character and began to create the first sonar data of the soil. Following their planned routes and taking the lake's depth and texture into account, the hydrographers on the *Surveyor* collected enough information to create a point cloud containing almost 135 million XYZ coordinates. All in all, the crew on the observation boat succeeded in recording all 2,855,204 square metres of the Klöntalersee in just five days.

Not only rapidly changing weather conditions and bone-chilling cold pushed man and machine to their limits, but the glaciated Glärnisch massif forming the lake's southern shore quite literally cast a 2,900-metre shadow and put the technology to the test. With the massif's steep slopes in such close proximity to the water's edge, the experts feared they might lose their GPS stream due to signal opacity on the south side of the Klöntalersee. In that case, tachymeters placed on the northern and eastern shores of the lake would have determined the boat's position. However, because of the lake's elongated kidney-like shape, that would have caused serious problems in obtaining accurate details about the boat's position.

STEADY POSITIONING

By using the Leica Viva GS 16 GNSS antenna on the *Surveyor* the data recorded with the multibeam sonar could be assigned to the coordinates with centimetre precision. Thanks to the built-in SmartLink technology, the crew would still have been able to record high-precision data and receive GNSS correction data even if the GSM network signal would have been lost. Thanks to 550 channels, a state-of-the-art surveying engine and ultra-modern RTK algorithms, the data from both the Aibot X6 UAV and the vessel could be precisely assigned with the test results.

AIRBORNE SURVEYING OF THE SHORES

Shore situations are hard to capture for multibeam-equipped vessels due to their general design. In addition to that, the risk of damaging the sensitive and expensive sensor rapidly rises in shallow water and in proximity

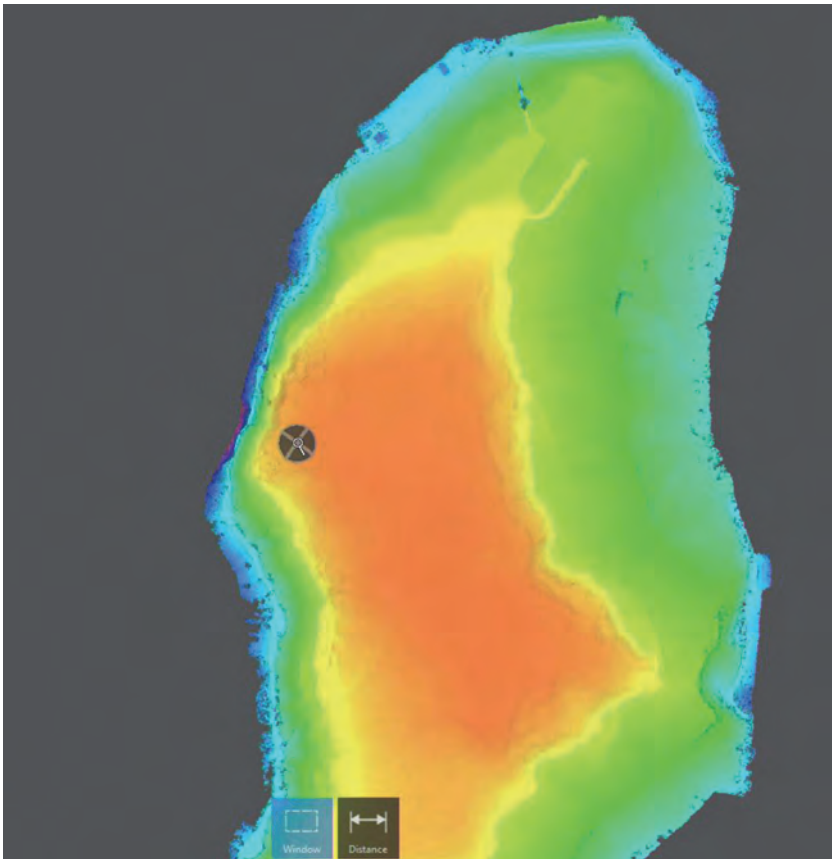


Figure 3, The lake's soil situation visualised in Autodesk Autocad Civil.

to the shore. In order to obtain exact results for the volume calculations and simulations in spite of this, the engineers drew on their experience with the UAV and decided to capture the shores and embankments via airborne photogrammetry.
After the lake was measured at regular water level from the boat, the engineers began to plan the flights of the Aibot X6 drone. To capture the shore regions overlapping with the measurements taken by the boat, it was crucial to fly the UAV at lower water levels. Once the level of the Klöntalersee had lowered seasonally, the survey with the hexacopter could begin.
To record the often angled and steep terrain of the bank area as precisely as possible, the experts decided to survey each area several times to increase the validity of their data. After the flight planning on the PC had been completed and the waypoints had been loaded onto the UAV's internal storage device, the ground control points (GCPs) around the lake were captured using the GNSS receiver so the first flights could begin.

CHALLENGING CONDITIONS

Once again, the surveying of the alpine reservoir presented its very own challenges for man and machine. In addition to average below-freezing temperatures, rapid weather changes and low clouds, the southern bank of the Klöntalersee with its steeply sloping mountain walls once again posed the biggest challenge. The UAV had to take off from and land on a separate boat because the steep walls and the dense vegetation along the shoreline made it impossible for the pilot to operate from the land. In addition to the sensitive and reliable technology, the pilot's skills and steady hand were particularly important.
Despite the adverse conditions, the team from Karlsruhe was able to collect highly precise data in 18 flights, so the dry shore strip with a total length of over 12 kilometres was covered within two days. With a picture taken every two seconds and the drone moving with 4m/s, the experts ensured that the data was recorded with the highest accuracy by the camera attached to the flying multisensor platform.
As with the recordings of the surveying boat, it was of the utmost importance for the UAV-based results to be accurately referenced. For this purpose, the Ingenieurteam GEO experts used the Aibot HP GNSS 2 RTK/GNSS module (L1/L2) and the Leica GNSS receiver. This proved to be a good combination for working under such difficult conditions to achieve an accuracy of 1-3cm in georeferencing the collected data.

POST-PROCESSING THE DATA

After all the measurements had been performed, the surveying experts began to process the obtained data. The point clouds created by the multibeam sonar had to be fed into the PDS 2000 bearing software to manually edit and correct them for errors. In order to integrate the shoreline data into the volume calculation, all 4,400 high-resolution images from the UAV had to be imported into Aibotix AiProFlight where they were merged with the coordinates from the UAV's log file. After that, the georeferenced data was edited in the AgiSoft PhotoScan Pro post-processing software to create a three-dimensional model as well as a point cloud. Subsequently, the two 3D models were combined in the Autodesk application AutoCAD Civil 3D to generate an exact model of the lake (Figure 3).

RELIABLE 3D MODELS

Using the data from the 3D model, the engineers generated a precise map with elevation lines for their client. The engineers stepped up to the plate and found the right tools to get the job done, combining two completely different ways of surveying large and challenging areas to generate precise results. With the data generated by the boat and the UAV, the experts were able to meet their client's needs, whether they wanted a detailed virtual 3D model or a printed plan including contour lines.

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SOUTH

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light but bigger screen and faster speed

ACHIEVING SUBDECIMETRE ACCURACY IN ARCTIC CANADA

Northern Survey Flights

To increase capacity at Pangnirtung Airport, situated in a remote mountainous region of northern Canada, one solution could be to relocate the airport to one of two nearby sites. This article provides insight into how unmanned aerial systems were used in a preliminary engineering survey of both sites. The project achieved an accuracy of less than 10cm, despite the challenges including GNSS signal interference and difficult, rocky, rugged terrain.

Even for experienced pilots, landing an aeroplane at Pangnirtung Airport on the remote Baffin Island in Canada's Nunavut province is at best a challenge; at worst, it is impossible. The airport is, however, the only reasonable way to reach this growing Arctic Circle community. Its capacity needs to be increased, but there is no room for runway expansion. One of the initiatives to address this issue would involve relocating Pangnirtung Airport to one of two sites on a plateau at 680m (2,230ft) above the town.

SURVEY SET-UP

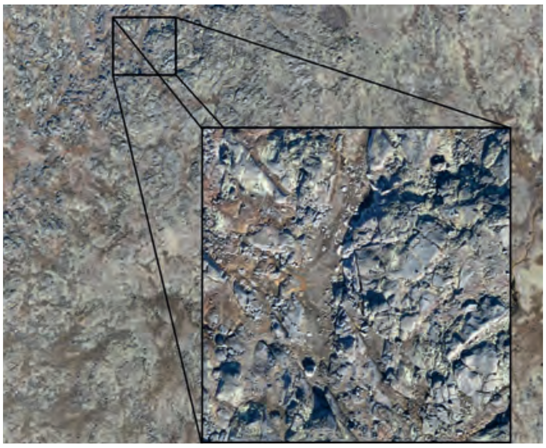
At each of the two sites, a high-resolution preliminary engineering survey was required on which a detailed airport design could be based. These surveys also had to achieve a high level of accuracy: a vertical root mean square error (RMSE) of less than 10cm. Furthermore, since the terrain was so remote and rugged – accessible only on foot – the data had to be in order on the first attempt. As a result, a reliable, accurate system that could be taken into – and launched from – the field was needed.

Equipped with RTK base stations, backpacks, sturdy shoes and senseFly eBee unmanned aerial vehicles (UAVs or 'drones'), a team from the Canadian geomatics firm Ventus Geospatial performed the survey. Ventus has significant drone experience, having conducted over 4,500 eBee flights to date. The firm operates a fleet of drones from several manufacturers and recently became the first company to meet Canada's stringent criteria for unmanned flight under BVLOS conditions. Ventus chose to fly eBees for the Baffin Island project due to their practicality and functionality, as well as their ability to deliver repeatable, reliable products.

The technique chosen was photogrammetry using the onboard camera from the eBee. Lidar was considered as an alternative in view of its good level of vertical accuracy:

▲ *Launching the eBee.*

▲ *RTK base station used to send corrections to the eBee RTK.*



▲ *Example of the high orthophoto quality achieved.*

▲ *One of the potential sites for the new airport.*

10 to 15 centimetres. However, the client demanded under 10cm, which was shown to be possible with the eBee (4cm for X,Y and 8-9cm for Z) at around a third of the cost of Lidar.

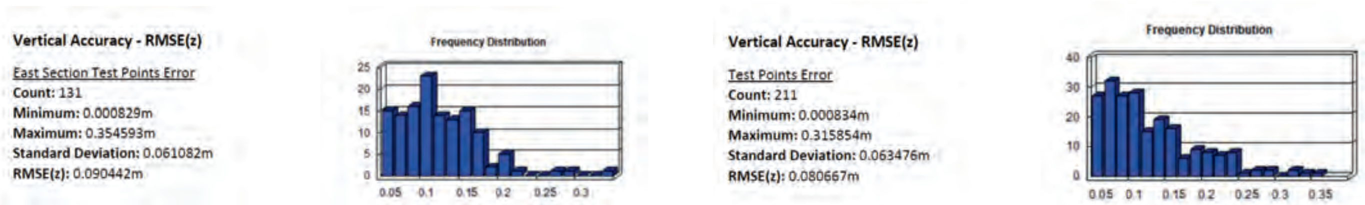
To achieve the optimal balance between accuracy, resolution and flight coverage of the eBee's S110 RGB cameras, a ground sampling distance (GSD) of 4cm per pixel was set, resulting in flights of 120m above ground level, covering 0.55km2 each. This relatively small-sounding coverage figure was a result of not only the flight height but also the high level of image overlap configured – 85% longitudinal and 80% lateral. This was necessary to ensure the quality of the resulting digital terrain model (DTM) and orthomosaic.

In total, four members of staff spent 16 days working on site. The project's two drones captured a total of 16,000 photos, covering Site 1 (25km^2) in 54 flights and Site 2 (15km^2) in 42. Back in the Ventus office, three data processing experts worked for ten days – a total of 30 man-days – accumulating around 280 hours' worth of image processing time to create the project's core outputs.

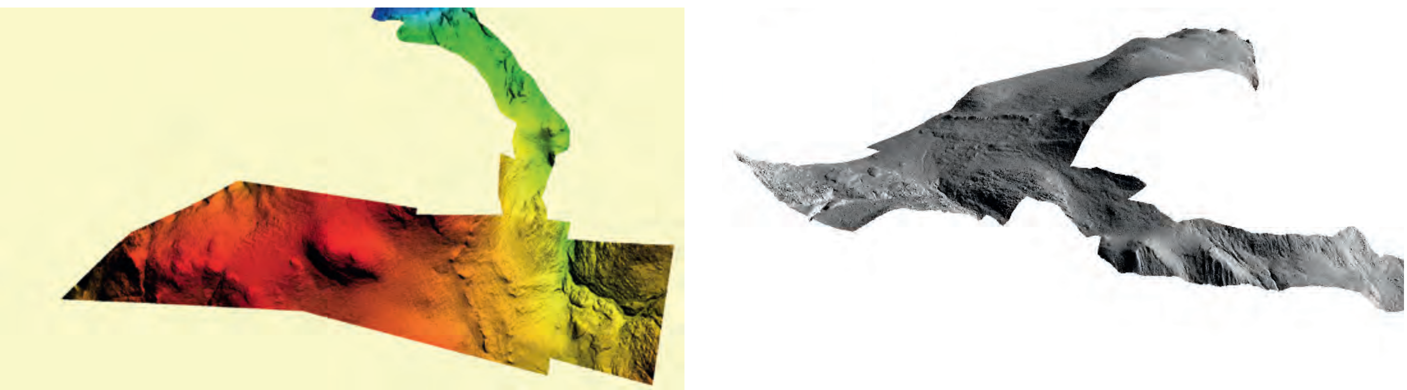
SURVEY CHALLENGES

In the field, Baffin Island was a project full of challenges. For example, in locations so far north, GNSS signals arrive from near the horizon and can be badly affected by the ionosphere. The most recent receiver including GPS and Glonass technology is needed in both base and drone, along with strict quality controls to keep absolute accuracy levels high. For this survey the minimum elevation mask of the receivers was set between 10° and 13° instead of the more customary 15°. Quality controls ensured that only measurements were recorded where the geometric dilution of precision (GDOP) value allowed a Z error of under 3cm.

Due to the RTK capability of one of the two eBees used, a large part of the ground control point (GCP) setting which is customary for photogrammetry could be eliminated for those areas surveyed by that eBee. Although the need to measure over a very large area of terrain made a full GNSS survey with RTK base stations unfeasible, they were employed alongside the drones to set GCPs and measure checkpoints. Before sending the drones into the air, both of the project's



▲ *Ventus Geospatial's accuracy results for Site 1 (left) and Site 2 (right), based on measured checkpoints.*



▲ *Elevation model (left) and digital terrain model (right) of the second site.*

▲ *Measuring one of the 300 ground control points.*

two-man survey teams set out on foot to set some of both sites' pre-planned GCPs (100 and 200 respectively). These GCPs were laid out in a grid right across the sites, ready to be used as a solid, accurate data reference. Once the drones were in the air, one of the teams continued surveying GCPs to completion, at which point they started flying too.

With the eBee RTK itself, the base station providing RTK corrections to the drone was placed for one area on an existing monument. For the other area, 8-9 hours of logging raw data with subsequent post-processing of the static survey information tied the information into a known geodetic reference.

The mountainous terrain poses a challenge not only to real-life pilots, but also to the eBee. Using the virtually global coverage of the elevation data built into the flight planning software accompanying the eBee (eMotion), however, the drone flight plans could be optimised for the local topography even out at the most remote corners of each site.

RESULTS

From the data, a DTM of 25cm-interval contour lines as well as highly detailed orthoimages were produced for both sites. Ventus Geospatial put significant effort into ensuring high absolute accuracy over the project's entire 40km^2 zone. After setting 300 GCPs and more than 340 additional checkpoints – measured with 2-3cm accuracy relative to the base station – these efforts paid off. Ventus achieved a level of vertical error (RMSE) well below the ordinarily acceptable 3 times GSD (i.e. 12cm). Both Ventus and the client consider the error observed to be a reflection of the very successful application of the technology in difficult, rocky, rugged terrain. ◀

ABOUT THE AUTHORS

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PILOT IN CZECH REPUBLIC ATTAINS HIGH-PRECISION RESULTS

UAS Photogrammetry and **Railway Mapping**

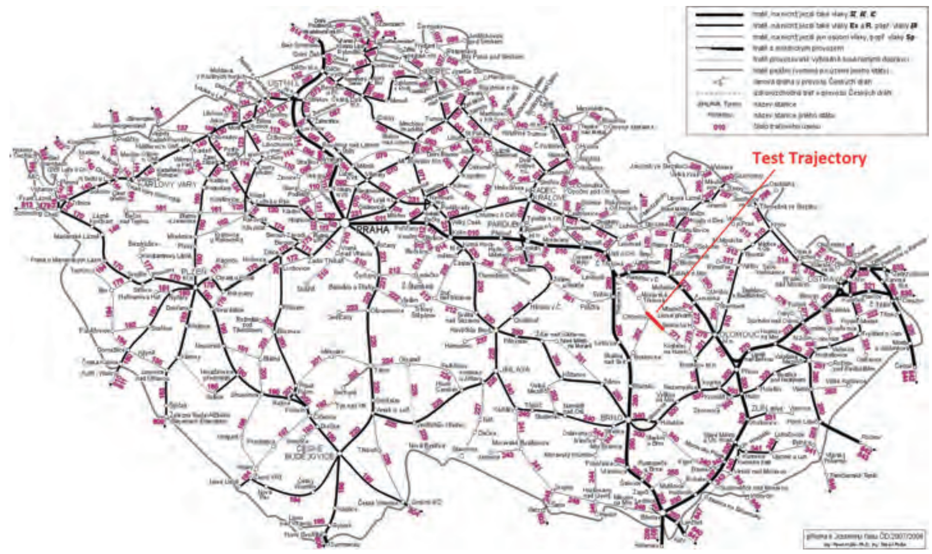
Today's photogrammetric software is able to create dense and precise digital surface models (DSMs), digital elevation models (DEMs) and orthoimages. But is the accuracy sufficient for highly demanding railway applications? The authors demonstrate in a pilot project carried out in the Czech Republic that unmanned aerial system (UAS) photogrammetry has great potential for collecting geodata meeting railway companies' high standards of precision. Parallel computing based on 16 personal computers (PCs) was used to process the 11,000-plus images in a reasonable time span.

Safeguarding the continuous operation of rail traffic entails maintenance of the rails, sleepers and gravel beds, design and construction of extension works and monitoring of the condition of railway bridges, among many other activities. All these tasks require the efficient and regular measuring and mapping of railway trajectories and their surroundings. Ground surveys can interfere with the train timetables, causing delays and dissatisfied travellers, plus they are expensive. An alternative geodata acquisition technology that does not interfere with railway operations is aerial photogrammetry. Manned airborne surveys, especially when they have to be carried out on a regular basis, are costly. A feasible alternative might be the use of a UAS. In cooperation with the Institute of Geodesy and Mine Surveying at the Technical University of Ostrava, Upvision conducted a feasibility test (Figure 1).

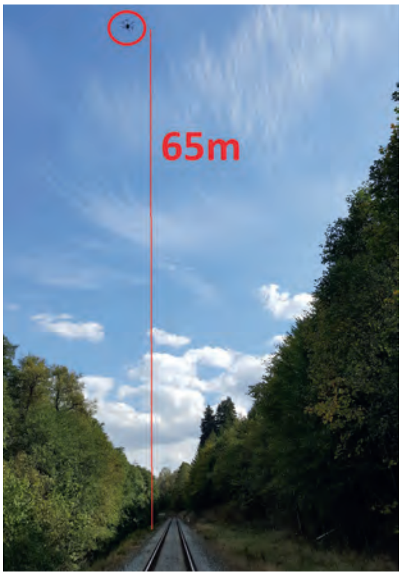
TRAJECTORY

The test focused on finding out whether UAS photogrammetry is able to attain the high standards of precision required for mapping railways and surrounding objects as set by the Czech Railway Infrastructure Administration (RIA). The mapping products should obey RIA's class-two and class-three accuracy standards, i.e. positioning precision of 4cm and 6cm respectively. A non-electrified single-track railway in Drahany Highlands was chosen as the test trajectory (Figure 2). With a length of 13.7 kilometres the track covers a variety of landscapes. It starts with open, flat agricultural fields lying at an altitude of 310 metres above sea level with many bends. After about four kilometres the track enters a narrow valley with steep slopes covered by tall spruce stands. Moving deeper into the valley, the track climbs up to an altitude of 505 metres. Over the final two kilometres the track descends and passes through pasture landscapes.

▲ *Figure 1, Preparing to set up a UAS photogrammetric survey of a railway track.*



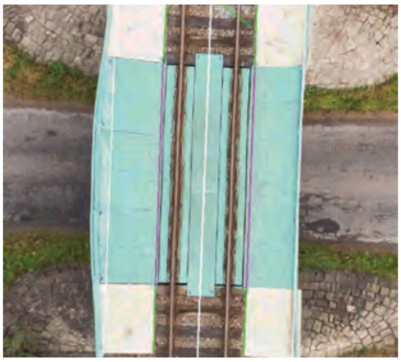
▲ *Figure 2, Map of the Czech railway network indicating the location of the test trajectory.*



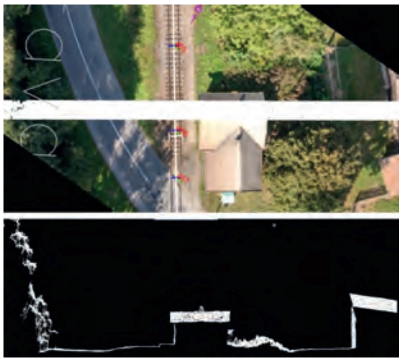
▲ *Figure 3, UAS in operation around 65 metres above the railway line.*

▲ *Figure 4, Railway station along the test trajectory.*

▲ *Figure 5, Ground control point (GCP) marked on a railway sleeper.*



▲ *Figure 6, Rail axis determined in the orthoimage.*



▲ *Figure 7, Profile across a railway track (top) and the corresponding DSM point cloud.*

SURVEY

The test area was flown with a modified Mikrokopter Hexa XL equipped with a calibrated Canon EOS 700D camera in early September 2016. The camera has an image size of 22.3 x 14.9mm, an effective resolution of 5,184 x 3,456 pixels and the lens is a Canon EF 28mm f / 1.8 USM. To obtain a ground sampling distance (GSD) of 1cm the average flying height had to be set at 65 metres (Figure 3). Three parallel strips were recorded. The middle strip captured the axis of the railway, while the two lateral strips captured the surrounding area, including buildings (Figure 4). The along/across-track overlaps were 80%/60% while two images per second were taken. A total of 43 flights were conducted. Each flight covered a track with an average length of 350 metres. To enable the entire trajectory to be processed as a single block, tracks were captured with an overlap of 50 metres. In total 11,391 images were recorded, each covering an area of about 52x35 square metres, i.e. approximately 1,800 square metres.

GCPS AND CHECKING

Accurate ground control points (GCPs) form the foundation for obtaining the high standards of precision required. They must be well distributed over the entire track in sufficient numbers. Therefore, a total of 173 GCPs were established along the track and measured using total stations. The angles and distances measured with the total stations were transferred into 3D coordinates in the national Czech coordinate system (JTSK) system used by the railway company. The GCPs were marked in the field with fluorescent-green circles of 3 to 4cm in diameter, which is 3.5 times the size of the required GSD (Figure 5). The marking was done by one field worker over two days. To quantify the quality of the UAS photogrammetric end products, the railway authority RIA provided a dataset of coordinates of railway points as well as a list of coordinates of points of objects alongside the railway line. These points had been obtained through ground surveys using total stations and were used to determine the precision in terms of root mean square error (RMSE). Furthermore, 3D drawings of the railway tracks were provided in Bentley Systems' DGN format and accessed with MicroStation V8i. They were used to compute the accuracy of the track axis determined from the UAS imagery (Figure 6).

ORTHOIMAGE AND DSM

The images were processed in multiple steps resulting in the following end products: DSM, DEM and seamless orthoimage. Various software tools were used in the subsequent stages. Agisoft Photoscan Professional was employed for creating tie points, identification of GCPs and checkpoints, adjustment of the interior and exterior orientation parameters and the creation of the DSM. Trimble INPHO module DTMaster was used for DSM and DEM editing, and OrthoMaster and OrthoVista were used for orthorectification and seamless orthoimage creation. Figure 7 shows a point cloud profile taken from the DSM.

PARALLEL COMPUTING

To guarantee the highest possible accuracy, all images were processed in one single block. Processing such a big block consisting of over 11,000 images on a single computer would take two to three months of non-stop computation time, which is of course impractical. Therefore, a computer network of 16 similar PCs (Intel Core i3 – 6100 CPU, 3.7GHz, 8GB RAM) was established. The computations using Agisoft were processed in a distributed way. The computation of the DSM, DEM and orthoimage required 1,385 machine hours in total.

RESULTS

The planar coordinates of 1,375 checkpoints were measured in the orthoimage with a GSD of 1cm and the corresponding heights of the points were derived from the DSM. The DSM was superimposed with the orthoimage to improve identification of the points. The distance between the orthoimage points and corresponding checkpoints was less than 20mm for 80% of the points, 89.4% of the points deviated less than 30mm and 96.5% less than 40mm. Hence, with a GSD of 1cm, a precision of class two could be attained and the precision of the height of flat terrain even surpasses class-two requirements. A GSD of 1cm is of course extremely high. To test whether lower GSDs would still provide results which meet the railway company's standards, the images were resampled at a GSD of 2cm. Those tests showed that objects such as crossings, sleepers, platforms and buildings can be mapped with a planar precision of 4cm and a height precision of 6cm, which corresponds to accuracy class three according to Czech standards. To further scrutinise the feasibility of UAS photogrammetry for railway applications, simulations were performed in which the numbers and configurations of GCPs and checkpoints were varied. The outcomes will help to develop guidelines for using UAS photogrammetry for railway mapping.

FUTURE

Now that this pilot project has shown the feasibility of UAS photogrammetry for railway mapping applications, guidelines for measuring coordinates of points can be developed according to the accuracy classes required. In addition to the creation of DSMs, DEMs and orthoimagery, products derived from overlapping UAS images allow volume determination of pits or dumped material along the railway line. The resulting end products can also be used for simulating train rides, detecting concealed spaces and optimisation of the placement of railway traffic signs such as speed limits. UAS photogrammetry can furthermore be used for regular inspection of railways and their surroundings in order to, for example, identify displacements of rocks and potentially unstable rock/soil formations, to check slope stability and to detect changes in the terrain. ◀

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INTERVIEW WITH MICHAEL DE LAGARDE, CEO, DELAIR-TECH

High-end UAVs: A Key Link in the Value Chain

Unmanned aerial vehicles (UAVs or 'drones') have become an essential tool for land surveyors. The geospatial industry is turning to drones to map the environment, which is also impacting the commercial UAV business. Delair-Tech is a prominent company in the industry and attracted particular attention when it acquired Gatewing from Trimble in 2016. *GIM International* interviewed Michael de Lagarde, CEO of the France-based company, to ask him about the company's strategy, outlook on the UAV market, cameras, fields of application and much more.

You recently announced that 2016 was a record year for Delair-Tech. Does that mean that the professional UAV industry is booming?

Over the past six years the commercial UAV technology has evolved quickly, preceded by the developments in recreational drones on the consumer market. Commercial machines have now reached the appropriate standards in ergonomics, safety and data quality. The legislation has followed the technological progress. Europe, and especially France, has been a pioneer, joined in 2016 by the USA with the release of Part 107: a set of rules that lays the foundations for the commercial use of drones. Every country in the world is following this path. 2017 will be the year of market adoption. Many industries have tested the tailored solutions that were designed specifically for their fields of activity, and have discovered that they add significant value. They are now convinced and ready to deploy on a large scale.

You have defined three strategic priorities for 2017. Can you tell us more about them?

Certainly. The first of the strategic priorities is structuring the commercial offer around verticals to continuously improve the value proposition to the final customer. In each of these sectors – power & utilities, geospatial, mines & quarries, oil & gas, railways & roads, emergency, security & defence, and agriculture & forestry – Delair-Tech proposes a specific solution, so that the drone-based tool chains are integrated seamlessly into the current processes of industrial users, with the highest possible added value. The second priority is to continue the R&D effort. The objective is to capitalise on Delair-Tech's field experience and create second-generation drones and associated data-processing software – more efficient and best adapted to the specific needs of large industrial groups. The third priority is international business development. Our company will continue to expand and strengthen its global network for the distribution of hardware and software. We will also focus on developing our service offerings worldwide, responding to the demand of industrial customers who wish to benefit from this technology without bringing drone operations in-house. Delair-Tech offers its customers experienced specialists to provide them with turnkey deployment solutions, while ensuring the safety of the operations and the quality of the results.

There are many developers of professional UAVs. What makes Delair-Tech's UAVs different from other manufacturers' UAVs?

Delair-Tech provides end-to-end drone solutions including hardware, software and services. Through a single interface, our industrial customers get the best fit-for-purpose drone solution to help them make informed decisions and boost their productivity thanks to aerial data turned into actionable business intelligence. On the hardware side, Delair-Tech's drones are long range. They are the only ones in the world certified for operations beyond the visual line of sight (BVLOS) and equipped with professional-grade payloads, from photogrammetric cameras to Lidar. The range of available products is one of the widest on the market and meets the majority of industrial customers' needs. On the software side, our cloud platform is simple and efficient. We have experience with paying customers since 2012. This is mainly due to French aerial regulations which have authorised professional UAV activities since 2012, whereas the legislation has been very restrictive in other countries. Therefore, Delair-Tech masters the entire drone technology value chain, from hardware to application-specific data processing. The results are highly integrated products delivering high added-value data. This advantage has been a key differentiator in the extremely competitive drone market and has enabled Delair-Tech to become a 'one-stop shop' for drones for commercial use.

With new companies emerging all the time, the UAV market still appears to be soaring. Do you agree?

Six years ago, the UAV landscape was mostly populated with small groups of hobbyists or academics, each developing their own prototypes. Requiring only a limited initial investment, small UAVs were generating much enthusiasm and hence rapidly gained in popularity. However, while it is certainly an achievement to get a demo version to fly once, developing machines that can be produced on a large scale and flown for

hundreds of hours requires tremendous effort, time and investment. In the face of this tough reality, the UAV manufacturing population has drastically shrunk since then. Today, platform manufacturers have become scarce, on both the recreational and the professional markets.
The recreational UAV market is now saturated, with few prospects. The race is over and clear leaders have emerged. The market is dominated by mass producers that are engaged in a price war, while the bubble is progressively deflating…so the focus is now shifting from leisure drones to commercial drones. B2B customers require credible partners, capable of delivering effective solutions in a reasonable time – hence the trend towards industrialisation and consolidation, while the smallest business or academic actors are progressively disappearing. There is currently a lot of hype about the data processing software part which appears to be carrying a large part of the added value along the chain, but the end customers are focused on finding efficient end-to-end solutions and the software is only one part of that.

▲ *Michael de Lagarde.*

UAVs are often equipped with cameras that don't match the quality of stable metric cameras. Which developments can we expect in this area?

Consumer cameras are inexpensive and yield data with a quality that is fit for an entry-level UAV. Of course, a number of basic tasks can be achieved using consumer-grade UAVs. However, in all data processing workflows, the quality of the input is crucial to the quality of the results – hence the importance of the hardware that captures the raw data. At the end of the day, people want the best possible result for their business analysis. The best way to achieve that is to consider the data processing chain as a whole, and to optimise each link. The first link is the hardware, and optimising this often results in using a high-end UAV rather than an entry-level one. High-end UAV cameras need to be adapted to a demanding set of constraints: high dynamics, vibration, changing lighting conditions, and to produce photogrammetry-grade data with high resolution and reduced blur and distortion. Sensitivity of the sensor, aperture time, resolution, optics…everything is optimised to produce the level of quality required for a specific application. Sensors are integrated into the on-board system and can be controlled from the ground by expert operators, and the data quality can be checked in real time throughout the entire acquisition process. The capacity of a UAV company to design its own photogrammetry sensors results in a product with a high level of integration, facilitating workflows for optimised data quality.

Capturing imagery is one thing, but after that it's all about processing and visualisation. How do those aspects work when using Delair-Tech UAVs?

All professional drone solutions are composed of two inseparable steps. The first is data acquisition: UAV operators deploy a mission-suitable UAV within the zone of interest. At this stage, special attention needs to be paid to safety, compliance with aviation rules and data quality. The output is a huge volume of unsorted raw data, i.e. big data, which is worthless unless it is processed in order to extract the valuable information. The second step is data processing using a software suite – a cloud-based platform with a simple and easy-to-use interface. The data is uploaded and goes through a number of processing steps, including quality control, photo-grammetry and business analysis. The output is data analytics – in this case a report containing the business-specific intelligence needed for the end user to act upon. Using an integrated drone solution, including both the hardware and software, simplifies the overall workflow and provides the best user experience.

You also offer a Lidar-equipped UAV. What are your expectations of UAVs carrying a Lidar sensor?

The expectation of many UAV-based activities is to reduce the operating costs of aerial data acquisition compared to the traditional methods, like planes or helicopters. With our Lidar product, we intend to combine the efficiency and the data quality of a VUX1 Riegl Lidar with the ease of deployment of a UAV. DT26X-LiDAR is particularly adapted for power line inspections or land surveying in large areas with dense vegetation. Typical accuracy (1 sigma) is less than 4cm along the

XY axis and less than 2cm along the Z axis, which opens up a large field of applications.

You acquired Trimble's UAV business and signed a strategic alliance with Trimble at the same time. Can you tell us more about that relationship?

In November 2016, Delair-Tech purchased Gatewing, Trimble's unmanned aircraft systems (UAS) business. Established in 2008, Gatewing has been active in the commercial UAV market for a long time and the company has pioneered UAV-based photogrammetry solutions. Through this acquisition, Delair-Tech intends to reach the critical size required to best serve the needs of large industrial groups in a market that is currently undergoing intense consolidation. Both companies have merged their teams and are creating synergy between their technologies, facilities and know-how, thus significantly increasing capacity for innovation and production. With a total workforce of 110 employees, the newly created group is one of the main players in the global professional drone market.

Alongside that acquisition, Delair-Tech and Microdrones have signed strategic commercial agreements with Trimble. Delair-Tech has teamed up with Microdrones, a long-established supplier of multirotor systems, to offer a comprehensive range of products. They jointly became official suppliers for Trimble's worldwide distribution network (150 dealers in 80 countries), which sells UAS and image-processing systems to the construction, agriculture, transport, geomatics and energy sectors.

You're also targeting the precision agriculture market. What are your thoughts on agriculture and UAVs?

We are targeting the digital agriculture market, which put briefly means getting precise and real-time crop insights so that the inputs can be aligned with the need of the plants in the field. Precision agriculture is still in its infancy, but the digital agriculture revolution is underway and UAVs are part of it. There was a lot of buzz around UAVs and agriculture, but sound and useful solutions are now emerging from the hype – ones that are really industrialised, that bring clear value and that fit in with daily agricultural or horticultural operations. For example, UAV solutions give seed breeders a tool that screens and describes the crop characteristics of entire research fields in a single flight – faster, with more precision and at a lower cost than conventional methods.

Which other fields of application does Delair-Tech consider to be very promising?

In addition to geospatial and agriculture, which are currently the most mature markets, we're also focusing on several other verticals that we consider very promising in the short term: power & utilities, oil & gas and surveillance. For the first two, the main applications consist of bringing innovative tools and solutions to enhance the recurring maintenance of infrastructure, i.e. the customers' major and strategic assets. In these markets, the drone is used as a substitute for traditional inspection and data collection methods such as on foot or by helicopter. The long endurance and BVLOS capabilities of the UAV, plus activity-specific software modules, are Delair-Tech's strong suit here. We offer mature products that have been tested, compared and proven to be more efficient than conventional methods over large distances (often several thousands of kilometres).

In the surveillance market, areas are patrolled to spot intrusions or malicious acts, so this differs from the other value propositions – survey, monitor & inspect – associated with maintenance tasks. Real-time surveillance requires a real-time video feed. At Delair-Tech, we have chosen to address a broad range of sectors instead of specialising in only one. Designing professional-level UAVs and data processing software requires massive investments. Addressing several markets at the same time, with technologies that have many commonalities, is a way to spread these investment costs over wider sources of revenue.

Which changes do you foresee in the coming years regarding the role of UAVs in the geospatial industry?

As the regulations and the technology evolve, the UAV will become a standard tool for the professional surveyor. Until now the market has been drawn to entry-level products, which is understandable at adoption time. But users are increasingly realising the limitations of these products and are migrating towards ROI-driven usage. For professional use, it is not just the UAV but the whole solution that matters. It is now acknowledged that UAVs are only a part of the entire value chain; higher-end products will be chosen if they increase the efficiency of the overall solution.

The need for 'drones as a service' is also developing in many industries. Infrastructure managers realise the potential of drone-based solutions in their daily work, but don't want to bring the activity in-house as it is not their core business. All this is a gradual and inevitable rationalisation and a normalisation of the use of these new tools that are progressively changing the way we work and helping us to move into the digital age. ◀

ABOUT MICHAEL DE LAGARDE

Frenchman Michael de Lagarde obtained an MSc in physics from École Polytechnique, Paris, in 2004. He started his career in the oil industry with Schlumberger as a wireline field engineer. As head of an intervention team, he managed the deployment of high-tech measurement tools during onshore and offshore drilling operations. Having first been based in Red Deer, Canada, he later moved to Yopal, Colombia. He subsequently became a petroleum engineer at Perenco, as offshore operations manager, in Egypt for the start-up of a gas production plant. When that project finished, he moved back to Paris and became part of the petroleum engineering flying team in charge of production optimisation at group level, with various spot assignations (mostly in East Africa). In 2010, he laid the foundations for Delair-Tech and developed the first UAV prototype. A year later he was joined by his three co-founders and they formally founded the company in Toulouse in March 2011.

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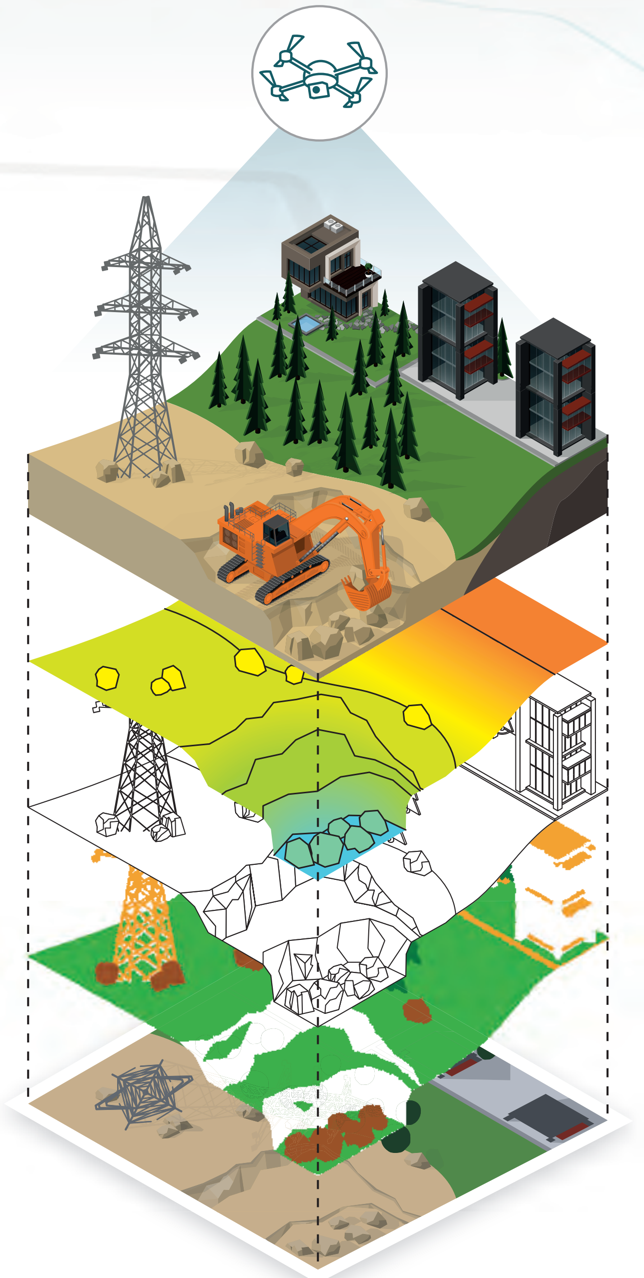

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3D MODELLING OF A CADASTRAL TREASURE

Towards a **3D Cadastre** in Slovenia

In the last decade, there has been a significant global trend towards 3D real property cadastres. Besides the legal framework, the modelling and graphical representation of 3D real property units have gained an important place on the research and development agenda. A Slovenian case is used to illustrate what a 'data treasure' is: the cadastral and other spatial data within the national spatial data infrastructure for generation of 3D real property graphical models within a 3D cadastre.

The roots of the Slovenian land administration system lie in the traditional parcel-oriented dual Austrian system, divided into the land surveying part (cadastre) and the legal part (land registry). The first systematic cadastral land surveying was carried out during the Austrian Empire, based on the *Grundsteuerpatent* (Land Taxation Act) from 1817. Initially established for taxation purposes, the land cadastre took on an important legal function with a formal linkage to the land registry in 1871 with the *Grundbuchsgesetz* (Land Registry Act).

Records and registration of property rights related to land and buildings originally only used 2D representation, based on parcel boundaries and building footprints. This was a major simplification of real property models. The use of land would of course be impossible if rights applied to the surface of the Earth only. A right to own or use land determined by parcel boundaries has always been related to a 'certain space', theoretically vertically extended from the centre of the Earth to the infinite sky, but always also restricted in the vertical dimension by other rights such as mineral and water rights, flying rights, etc.

Although real property units have always been 3D entities, their 2D graphical representation (cadastral maps) enabled transparent registration of real properties in most situations. With the increasing complexity of our built environment in particular, a requirement for additional vertical (along with the horizontal) division of space and determination of 3D real property units has emerged in the last decades. This calls for new concepts and approaches to modelling real property units within a land administration system.

LAND PARCELS AND BUILDINGS

The main principle of the current Slovenian real property legislation continues to be the Roman principle of superficies solo cedit, i.e. the building follows the legal fate of the land. Exceptions to this principle are (1) the right of superficies, which is the right to own a built structure above or beneath the land owned by a third person, and (2) apartment ownership (condominium). These two exceptions require a technical solution for recording and registering buildings and parts of buildings as real property units. The 2D graphical representation of land parcels no longer met the requirements for transparent registration and representations in all real property situations, as prescribed by law. As a consequence, the Land Cadastre was upgraded with new records: the Building Cadastre, based on legislation from 2000. Both records are nowadays maintained by the Surveying and Mapping Authority of the Republic of Slovenia and are linked with the Land Registry at the Court of Justice.

CADASTRAL DATA ON BUILDINGS

In the period from 2000 to 2003, data was systematically acquired about all buildings in Slovenia. This entailed data about each building's exterior, namely the building projection to the ground, the highest point of the building and the point representing the terrain around the building, being extracted photogrammetrically from stereopairs of aerial images. In 2003 and 2004, attribute data from the available records was added to each acquired building represented by a polygon in the national reference coordinate system. Although officially graphically represented in just two dimensions, the data from the Land Cadastre and the Building Cadastre provided the data needed to generate a 3D cadastral representation.

However, since the vertical coordinates were recorded as attributes for limited points (buildings), the Lidar data available within the National Spatial Data Infrastructure for the whole Slovenian territory is nowadays an important input for 3D modelling of cadastral data at Level of Detail (LoD) 1 as determined by the CityGML OGC standard. The CityGML model, presented in Figure 1, was created using:

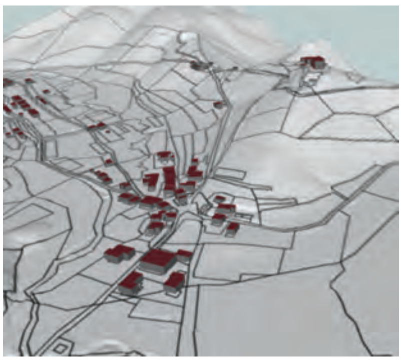
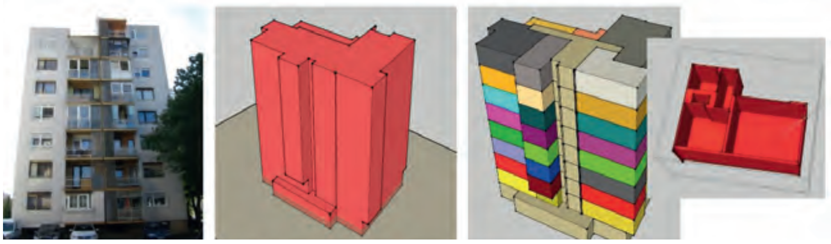


Figure 1, 3D model based on the CityGML standard (LoD1) using cadastral and Lidar data.



▲ *Figure 2, 3D models for a multistorey building based on cadastral data – from a 3D building model as a solid (LoD1) to detailed 3D models of parts of the building (apartments and common spaces).*

- data from the Land Cadastre (parcel boundaries, building footprints)
- data from the Building Cadastre (vertical projection of the buildings on the ground)
- a Lidar georeferenced and classified point cloud (with a density of 10 points per square metre – the first pulse).

This case study also illustrates an option for merging both records into one with the possibility of a unique 3D graphical representation of cadastral data.

3D REAL PROPERTY CADASTRE

Considering the requirements for transparent registration of 3D real property units, as can be defined within the Slovenian legislation, 3D graphical models should also be developed for 'complex' situations where real property units are defined with a vertical extension, e.g. example parts of a building. Before 2000, registration of property rights for an apartment or other parts of buildings was possible in the Land Registry based on a building and floor (apartment) sketch, providing appendices to the real property registration documentation. With the new legislation from 2000, the cadastral entry with floor plans and a georeferenced building footprint in the national reference coordinate system is a precondition for registration of rights and restrictions on buildings or parts of buildings in the Land Registry. For the cadastral entry, a drawing of each horizontal layer of the building, i.e. the floor plan, has to be provided. The collection of the floor plans explicitly covers the whole building.

The objective has been to provide 3D models for each real property unit to which rights, restrictions and other attributes can be assigned in the cadastres and the Land Registry. Based on the data from the Land Cadastre (building footprint) and the Building Cadastre (building outline, floor plans), the authors prepared a detailed 3D model of a selected building that had been previously divided into more real property units, i.e. apartments and common parts of the building (Figure 2).

Here, it has to be emphasised that the current cadastral archive at the surveying authority does not include vector data of floor plans; additionally, floor heights are missing. This data is therefore not publicly available, but it can be found at the archives of the land surveyors who provided the documentation for the cadastral entry. Recommendations to change the rules for recording and archiving cadastral data are currently under consideration at the surveying authority.

COMPLEX STRUCTURES

In urban areas and also in other areas with intensive human interventions, there is a tendency to use the space above and below the Earth's surface and above and below existing structures – not only in the case of buildings but also in the case of other engineering structures. While there is still a legal barrier to form and register a 3D real property unit which is not a building (e.g. a tunnel or a bridge), the approach presented for buildings can be applied in many situations.

For illustration purposes, the authors selected an underpass in Ljubljana. Currently, the underpass is recorded only as attribute data and a floor plan in archival documentation within the Building Cadastre and is not a part of the cadastral graphical representation (Figure 3). The graphical representation of the Land Cadastre and Building Cadastre data does not indicate that there is, in fact, an underground structure. The floor plans of the underground space are saved only as attributes linked to the documentation of the Land Cadastre, which provides the basis for registering the rights to real property units in the Land Registry. This complex data structure is, in such a case, difficult to understand, and a 3D model of real property units is required in order to achieve legal certainty in relation to registering real properties.

▲ *Figure 3, An underpass in Ljubljana with underground business units – the 2D graphical representation of the Land Cadastre and the Building Cadastre data (left) with the added plan of underground real property units (right).*

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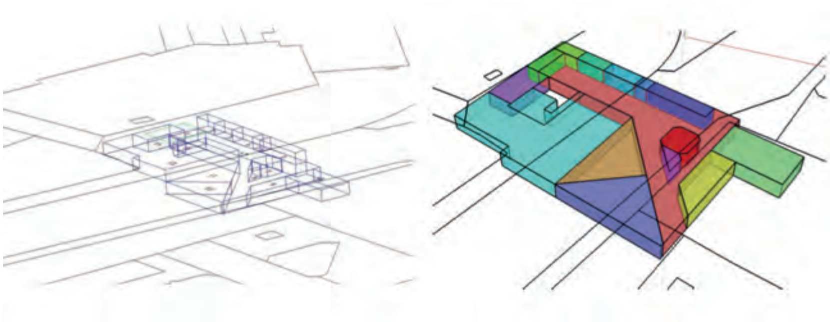
The data and documentation needed to register underground real property units in the Land Cadastre and further in the Land Registry were used to provide a detailed 3D model, including all real property units to which cadastral and registry attributes are assigned (Figure 4).

FURTHER CHALLENGES

The main challenge when trying to develop such detailed 3D models of real properties within the Slovenian land administration system is the incomplete Building Cadastre database. Detailed floor plans are available only for the buildings with the so-called 'cadastral entry' that is needed for new buildings and for registration of apartment ownership; for other buildings, only the data from the stereo photogrammetric acquisition is available. Furthermore, attention should be drawn to the data format and quality of floor plans in the Building Cadastre archive; most floor plans are still not directly available in vector format. Finally, in order to mirror the multifunctionality of the cadastre, the topology of 3D models must be considered further. This is a precondition to ensure topologically correct 3D models, and to use them for different types of spatial analysis, location-based services and other applications.

ACKNOWLEDGEMENT

The authors would like to thank Mojca Kosmatin Fras for her contribution to this article. ◀



▲ *Figure 4, 3D representation of property units in an underpass – a simple CAD model (left) and Google sketch model (right).*

FURTHER READING

Drobež, P., Kosmatin Fras, M., Ferlan, M., Lisec, A. (2017). Transition from 2D to 3D real property cadastre: The case of the Slovenian cadastre. *Computers, Environment and Urban Systems*, 62, 125–135, doi:10.1016/j.compenvurbsys.2016.11.002

Drobež, P., Grigillo, D., Lisec, A., Kosmatin Fras (2016). Remote sensing data as a potential source for establishment of the 3D cadastre in Slovenia. *Geodetski vestnik*, 60 (3), 392–422, doi: 10.15292/geodetski-vestnik.2016.03.392-422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GNSS MONITORING SOLUTION ONBOARD A STAND-ALONE RECEIVER

Autonomously Detecting **Fast Movements**

Diverse environmental effects, climatic changes and human alterations of the ecosystems are deeply changing Earth's surface processes and creating environmental challenges that researchers are struggling to address. This article describes how the new Leica Geosystems' Velocity and Displacement Autonomous Solution Engine (VADASE) technology helps scientists and engineers to receive actionable information about fast movements of man-made and natural structures as they occur. Running onboard a Leica Geosystems GNSS receiver, the autonomous solution assists professionals to take action, react, mitigate damage and protect life.

▲ VADASE application logo.

The use of a highly precise time-differenced phase observation enables the calculation of the velocity of a site location or GNSS antenna position respectively, which allows an accurate estimate of the movement. Time-differencing the phase observations is required to remove the unknown ambiguity parameter. This allows the processing of the observations without the need to do any phase ambiguity resolution and enables VADASE to produce a velocity estimate from any two epochs of phase observations. Error sources such as ionosphere, troposphere, linearisation errors and satellite orbit errors need to be compensated.

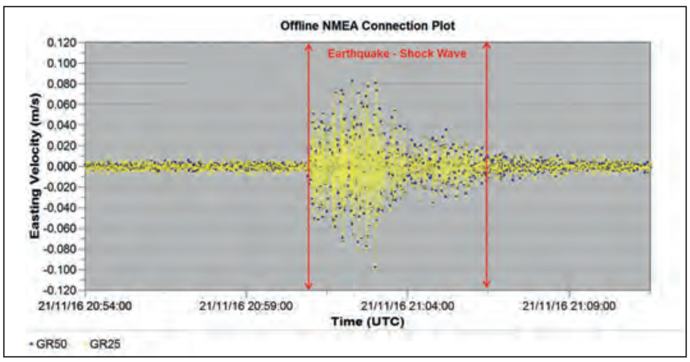
The ionosphere effects are mitigated by processing a linear combination – a common process to remove effects of ionosphere refraction, of GNSS signals – which mitigates the first-order ionosphere drift in the velocity solution, while a precise troposphere model is used to estimate and compensate for the troposphere drift. In the case of a single-frequency solution, a precise a priori ionosphere model is used to compensate for the ionosphere effects. The linearisation errors can also be minimised using two techniques:

1. The first is to linearise the set of equations around an accurate known point, such as the site coordinates of the GNSS antenna. These should refer to the GNSS reference frame and be accurate to some decimetres or better.
2. The second is to iterate the solution to further minimise any linearisation biases. If the site coordinates are unavailable or of insufficient quality, a single point positioning solution can also be used as the initial linearisation point.

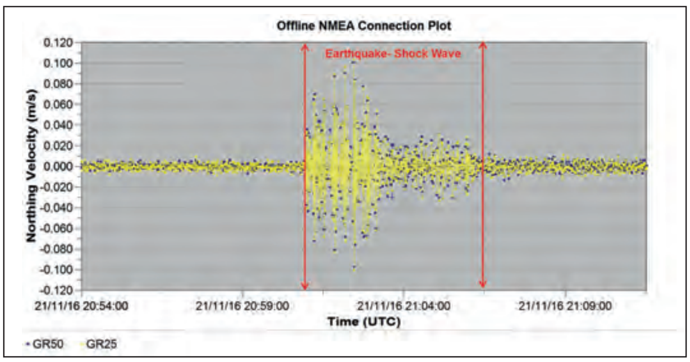
As VADASE is realised onboard the receiver as a real-time solution, the satellite orbit velocities required for the calculations have to be directly derived from the broadcast satellite ephemeris. As the observations used are time-differenced phase observations, these are actually the position difference between subsequent epochs, which equates to the average velocity over the given time period. Furthermore, since the velocities derived from the broadcast ephemeris are the instantaneous velocities at the epoch time, it is necessary to compensate these values to obtain the computed average velocity over the entire epoch. Thus VADASE also calculates the satellite acceleration and jerk to a high degree of precision in order to compute the correct expected average velocity term.

The displacements in the VADASE algorithm are computed by integrating the estimated

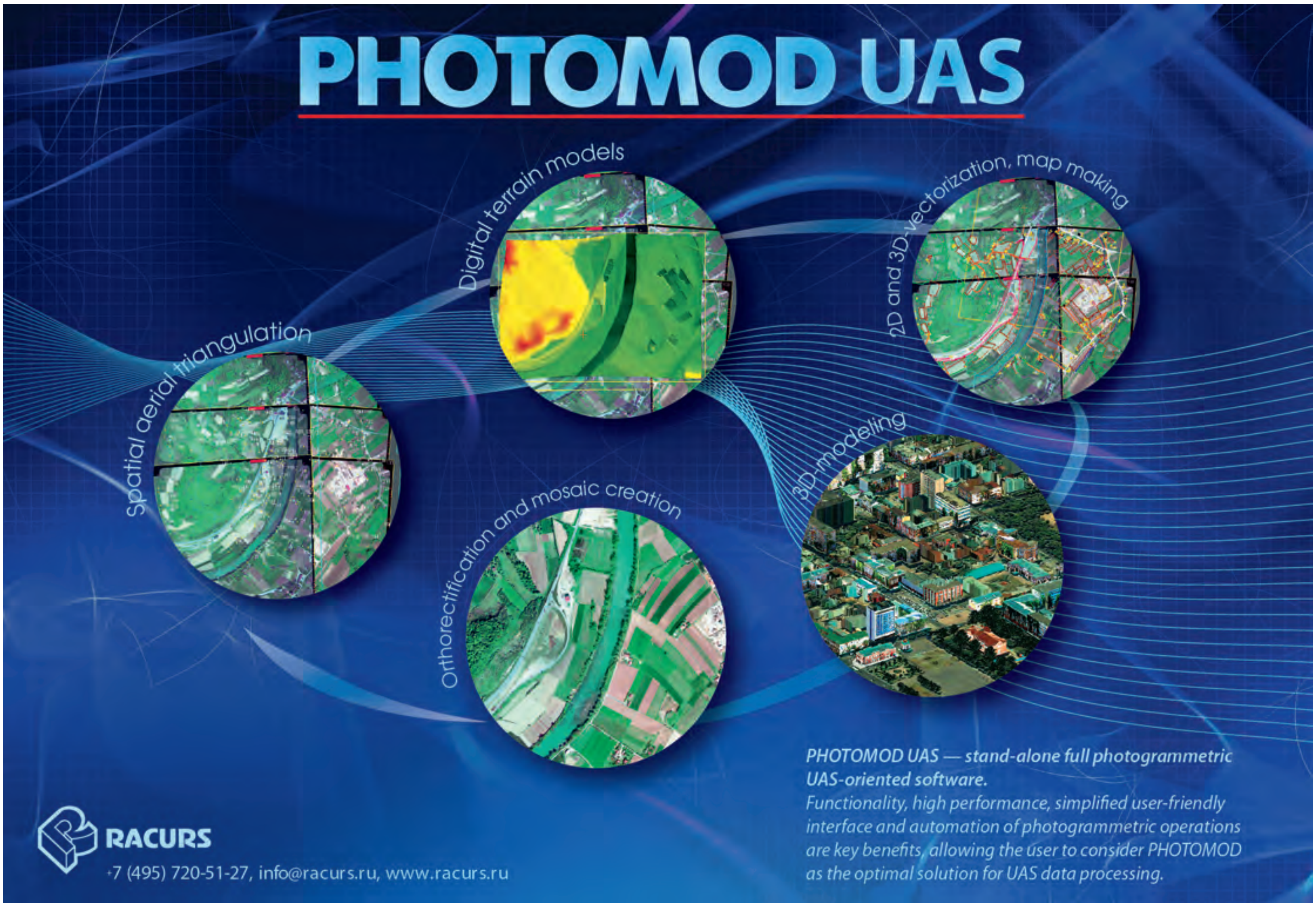
▶



▲ Namie earthquake: easting velocity observed in Tokyo.



▲ Namie earthquake: northing velocity observed in Tokyo.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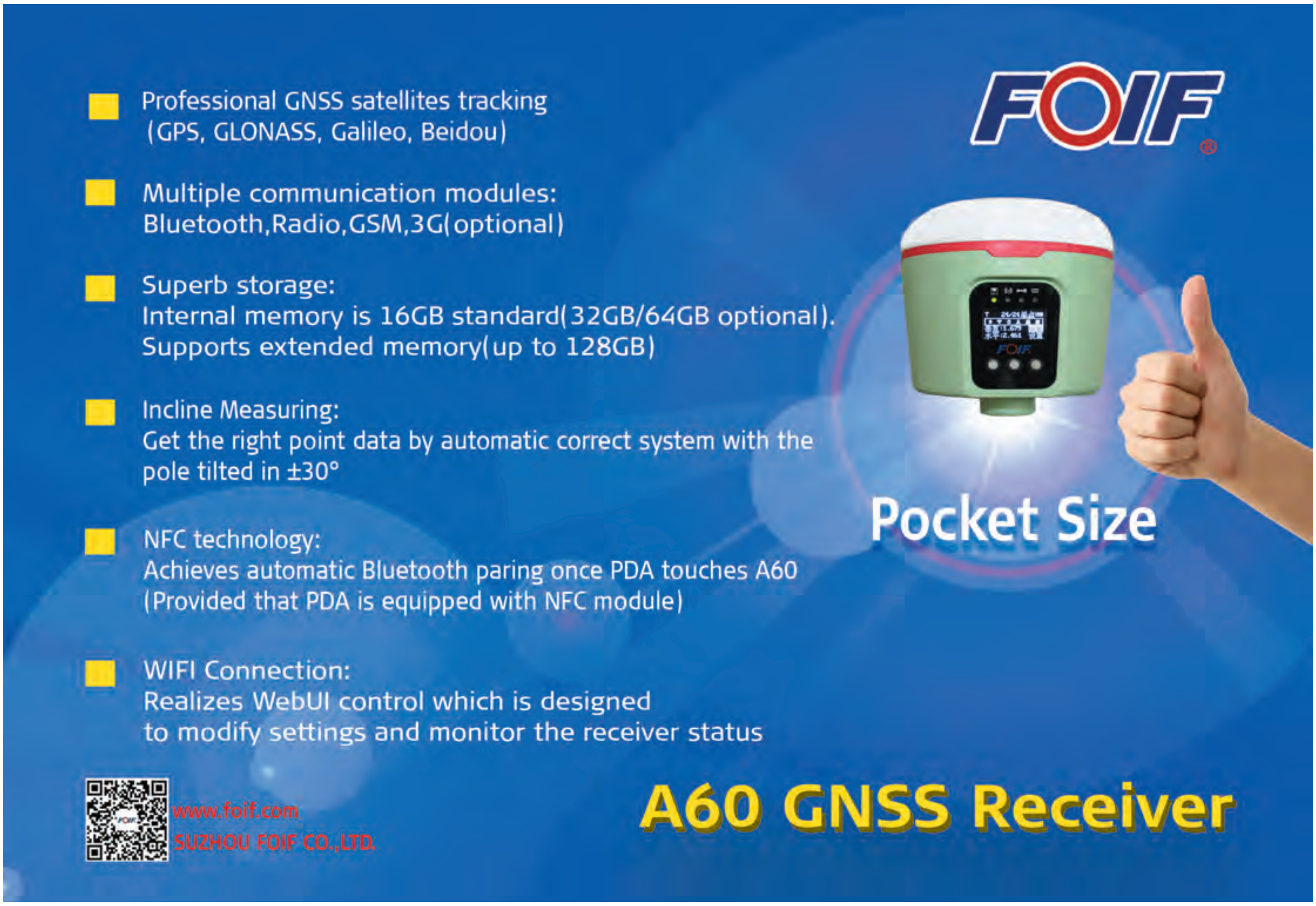
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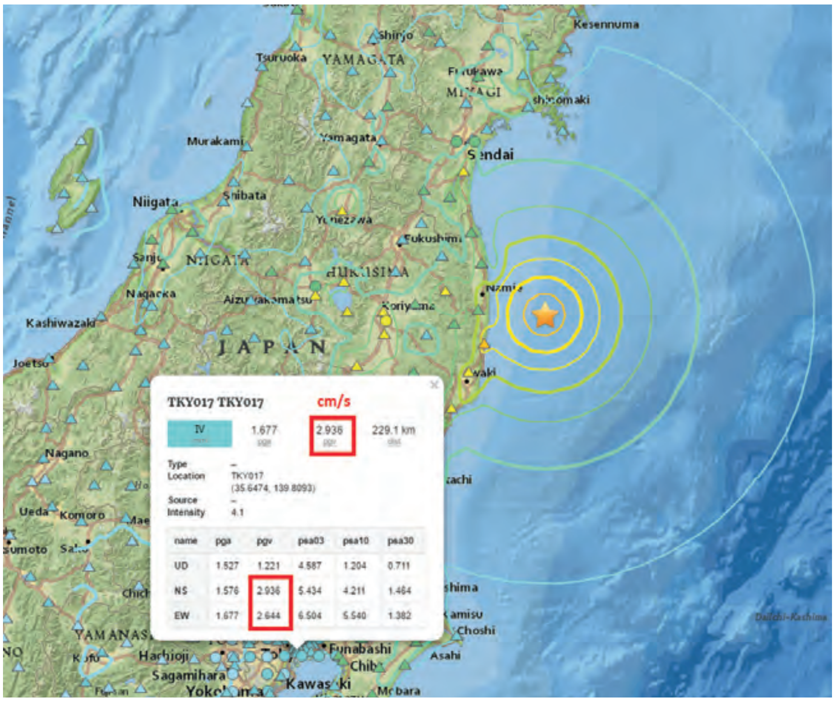

▲ *Namie earthquake data (cm/s) from the nearby TKY017 station (courtesy US Geological Survey).*

▲ *Leica GR50 GNSS receiver.*

velocities. Even with a perfectly stationary antenna, due to processing noise the estimated velocities will always be different from zero and will continually change by some small amount. Therefore, the integration step needs to differentiate between real movements and process noise.

Within VADASE a straightforward velocity noise threshold is applied to detect movements of the GNSS antenna and trigger the start and end of the displacement computation. Additionally, an effective outlier detection technique based on the velocity component 'quality estimates derived from the variances' detects and removes blunders from the raw velocity data. Depending on the desired application, different displacement computation strategies may be desired.

APPLICATION AREAS

The algorithm has been integrated into the RefWorx firmware of all current GNSS reference stations (GR series) and monitoring receivers (GM series). With this integration, the technology is now available for a wide range of GNSS users and applications, such as wave-form analysis in seismology and tsunami early-warning systems, real-time structural and geotechnical engineering monitoring and safety monitoring of infrastructures close to potential environmental hazards. As soon as predefined limits are exceeded, the responsible teams instantly receive a warning to take necessary action.

Displacement events are recorded onboard a single stand-alone GNSS receiver, and the user can be instantly notified by email. Unlike traditional GNSS monitoring systems that require additional hardware or infrastructure for differential processing (i.e. one or more reference stations or global correction services for precise point positioning), this technology provides autonomous processing capability with no extra equipment or services such as RTK needed.

TESTS

Earlier application studies, e.g. on the Tohoku-Oki earthquake from 11 March 2011, have demonstrated the effectiveness of VADASE. More recently, in the early hours of 22 November 2016, a 6.9-magnitude earthquake struck off the coast of Namie, located on Japan's Honshu island. A tsunami warning was issued indicating waves of up to 3 metres. The Leica Geosystems team was able to analyse the data taken during the earthquake from two independent GNSS test systems co-located and connected to the same antenna installed on the Leica Geosystems office building in Tokyo. The station is more than 230km away from the epicentre of the earthquake which was reported at 20:59 UTC. Nevertheless, the analysis revealed that the antenna had reacted to the earthquake from around 21:00:50 UTC onwards and that VADASE, which was not specifically set up for seismic detection, had recognised some small impact. This demonstrates the effectiveness as well as the sensitivity of the solution for the detection of earthquake occurrences.

Earthquake early-warning systems can use VADASE technology to alert scientists when shock waves generated by an earthquake are expected to reach their site location. In addition, for applications needing instant information about the impact on nature and infrastructure following seismic and natural disasters, the method can provide information on co-seismic displacements and waveforms for analysis. VADASE can provide valuable data on displacements when monitoring structures such as buildings, bridges and skyscrapers.

CONCLUDING REMARKS

When fast movements have to be detected and their effects suddenly evaluated, Leica VADASE can help researchers and engineers to make highly informed decisions immediately. The solution adds additional value to traditional GNSS monitoring, providing accurate velocity information based on a stand-alone GNSS receiver that is continually available in real time for precise and reliable analysis of fast movements. ◂

FURTHER READING

- Leica VADASE – White Paper: http://bit.ly/2o8bnap

ABOUT THE AUTHOR

Frank Pache received a graduate engineer degree in geodetics engineering from the University of Applied Sciences Bochum (Germany) in 1991. He joined Leica Geosystems in 1992 as an application engineer for GNSS surveying systems. He currently holds a position as senior product manager for GNSS infrastructure solutions.

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BY **FRÉDÉRIQUE COUMANS**, CONTRIBUTING EDITOR, GIM INTERNATIONAL

ITS4LAND

Improving Land Tenure Security with **Low-cost Technologies**

its4land is a EU-financed project to assist Kenya, Rwanda and Ethiopia in mapping land tenure more quickly, cheaply and transparently. It will end in three years' time; right now, the Africans and Europeans are in the phase of needs assessment. The focus is not on technical requirements, but on operational priorities and managerial context. The first results indicate that low-cost geospatial technologies will be helpful, not least because they also benefit priorities other than improving cadastral services.

The its4land project aims to adapt and validate a land-tenure recording suite based on small, fixed-wing unmanned aerial vehicles (UAVs or 'drones'), smart sketch maps, automated feature extraction and geocloud services. These tools have been applied in general mapping elsewhere. In this project they will, for the first time, be adapted for land administration use for the benefit of Kenya, Rwanda and Ethiopia. The aim is to help map land rights more quickly, cheaply and transparently for all stakeholders – women explicitly included. The first project phase is an assessment of the technical and non-technical user needs, as broadly as is relevant to meet sustainable development imperatives. Dr Serene Ho, working at the Public Governance Institute at KU Leuven in Belgium, is tasked with getting a good picture of those needs, connected norms and values and so on. Dr Ho explains the importance of this phase: "All three East African countries have different existing land reform projects, but success can be limited by a gap between formal processes and acceptance in communities. Land information is an engineering-dominated, technology-driven field. Most people think technology adoption is determined by rational drivers like cost-benefit analysis, but it is not the most efficient technology that will be adopted; it is the one that meets needs while also fitting with contemporary values. This kind of assessment will also likely lead to better outcomes for the latter parts of the project associated with governance and business models." The European Union is funding this project to the tune of EUR3.9 million. The its4land project is led by the University of Twente (The Netherlands). The academic partners are Münster University (Germany), Technical University of Kenya, Bahir Dar University (Ethiopia) and INES Ruhengeri (Rwanda), and

▲ *Dr Serene Ho: "It is not the most efficient technology that will be adopted; it is the one that meets needs while also fitting with contemporary values." (Photo: Jeroen van Berkel)*

▲ *Team members interview Maasai women in Kajiado county, Kenya. (Photo: George Osewe)*

▲ *The Rwandesian, Ethiopian and Kenyan partners have already received their first UAV training (in France). Placide Nkerabigwi, an engineering scientist from Rwanda, is one of the enthusiastic trainees.*

the companies Esri Rwanda and Hansa Luftbild are also participating. Products or services will be developed based on open-source technologies.

SOURCE OF CONFLICT

Worldwide, it is estimated that only 50 countries have complete and up-to-date national land registries in which each property has a verifiable owner and mapped boundary, and there is room for improvement in the tenure-recording systems in the three co-located East African countries too. In Ethiopia, the population mostly consists of rural dwellers (80 million people out of 100 million); only 25% of them have some form of land record and far less of the country is spatially mapped. A map of land tenures in rural areas could also support impending land consolidations as land fragmentation begins to undermine food security efforts. In Kenya (48 million people) cultural differences in land rights are a key source of conflict. Almost 10 million Maasai (and Samburu) pastoralists do not have means for demonstrating legitimate land uses and holdings. Cities are growing at a fast rate and that is disrupting all kinds of patterns: women cannot go to wells, and long-standing livestock herding routes are now blocked by privately held land preventing access to water and pasture. It is a growing source of conflict: in the face of worsening drought, pastoralists who have a communal approach to land use and access send their herds onto farmers' privately owned grassland. And, last but not least, Rwanda (population of about 13 million) managed to recently map and record its 13 million land parcels, but several million records – mostly from holders of tiny farms – remain untitled. Moreover, it must be ensured that all updates relating to land transactions can easily be recorded in official systems.

MATCHMAKERS

Politics and policies are the givens. "Our aim is to understand each country's current land tenure information needs, to identify which technologies will be most appropriate; we are matchmakers," states Dr Ho. For example, Kenya's customary tenure has been challenging to administer. The Maasai can define their boundaries using geographic features. They may say: 'Our land stretches to that mountain, then to the right until you get to that river'. The project is exploring how smart sketch maps might make a difference. "In its4land we are aiming to record such descriptions of large areas of land use through sketching. These will be processed so that they can be aligned with metric maps. This adds a socially constructed dimension of land tenure that is currently difficult for formal land administration systems to accommodate." While sketching is usually carried out on plain paper, it could also be done on top of a UAV image. At the same time, the project seeks to identify differences between women and men in their approach to sketching and in the data they produce.

BETTER CADASTRAL-BOUNDARY ACCURACY WAS NOT HIGH ON THE LIST OF PRIORITIES IN RWANDA

UAVs will certainly be of use in Kenya from other perspectives. The High Court recently overturned all land transactions since 2013 because it found that poor land information had led to a spate of erroneous or fraudulent titling. Many plots have an overlap; on large plots, it can be as much as 1 kilometre. Now the Kenyans have high hopes for the use of drones with the registration of land transactions. For instance in Kajiado county, one of the case locations for the project, the plots often comprise a few thousand acres and UAV-collected data could very well facilitate the survey process. UAVs are quick to deploy, the sensors have very high accuracy and a broad-wing UAV can fly for up to two hours.

PRIORITISATION OF NEEDS

Phase one – 'Get needs' – of the its4land project will conclude by June 2017. Government agencies at different levels, NGOs, academia and the private sector are engaged through workshops. Local communities tend to be interviewed separately. The emphasis of these activities is to arrive at a consensus around identification and prioritisation of the needs, as well as stakeholders' perceptions of the potential application of UAVs, smart sketch maps, automated feature extraction and geocloud services for those needs. At the time of writing, data collection has been completed in Rwanda and is in the final stages in Kenya. In Ethiopia, a national conflict has limited the research activities.

In Rwanda, the research revealed that boundary accuracy is still an issue for communities in rural areas particularly since plot area is a determinant for accessing agricultural inputs such as fertilisers. The need for updating land use rights as well as completing the registration process for untitled plots was also identified. For local governments, the need for improved access to digital cadastral data linked to the national master plan on land use was high on the agenda to be able to improve land-related service delivery.

Similarly, the national government prioritised the need to integrate other non-cadastral data with the cadastral map. Serene Ho: "The accuracy of cadastral boundaries could be improved, but that was – interestingly – not high on the list of priorities. Instead, the government wanted to leverage the cadastral map and connect this with other data: on infrastructure, utilities, history of land transactions, land use, national master plans, etc." To be able to combine 'basic' spatial data will improve decision-making around planning and development. Change is happening very fast because of urbanisation, so there is a need to be able to act accordingly based on a bird's-eye view of the land – spatially, geometrically and mostly attribute-wise. Also, there is a desire to capitalise on the investment (USD80 million) in the new cadastral system. Small plots and limited land resources demand a high-accuracy data acquisition tool that responds to these characteristics. For all those reasons, the UAV was a clear sell for Rwandan stakeholders. Better land tenure will be an important consequence of the technology, but Dr Ho concludes: "The value of the UAV was really recognised by the stakeholders to lie in the potential to use the data for other purposes."

UAVS HAVE ARRIVED

The second tool nominated in Rwanda concerned the geocloud services, given the identified needs around data harmonisation and data sharing. Smart sketch maps, possibly in combination with UAV images and automated feature extraction, could also play a role, particularly in facilitating community participation in planning. However, stakeholders also recognised barriers to adoption of the innovative geospatial tools that exist at individual, organisational and structural levels: specialised skills, outdated and/or non-digital information, the fact that there is currently only one registered UAV pilot in Rwanda, and availability of electricity and connectivity.

THE VALUE OF THE UAV LIES IN THE POTENTIAL TO USE THE DATA FOR MORE THAN JUST BETTER LAND TENURE

In the workshops, the stakeholders were also asked to give their opinions on market opportunities to realise additional funding for themselves with the new technology and the data acquired with it. Again the UAV scored best. Dr Rohan Bennett, director of the School for Land Administration Studies at the University of Twente, who is coordinating the UAV-related innovation for land administration use in this project, is pleased with the progress so far: "Within the context of its4land, the future UAV pilots from our Rwandesian, Ethiopian and Kenyan partners have already received their first training, which included map production from UAV images. And now the drones which form part of the project budget have arrived in each of the three countries. On-site support training and licensing will be next. its4land is getting its wings."

UN-GGIM Expert Group on Land Administration and Management

The UN-GGIM Expert Group on Land Administration and Management was hosted by the Dutch government in Delft from 14-15 March 2017. A total of 24 experts participated in the Expert Group Meeting, comprising ten expert representatives from member states, three from UN System entities, three from international organisations (including FIG) and four national organisations. In addition there were three observers and a staff from the Secretariat in attendance.

The attendees heard a series of presentations on issues such as globally recognised concepts, approaches and activities for good land administration including the Voluntary Guidelines for the Responsible Governance of Tenure, the Continuum of Land Rights and Fit-for-purpose Land Administration. The meeting also informed participants about the ISO 19152 Land Administration Domain Model, Social Tenure Domain Model and the activities of Open Geospatial Consortium (OGC) Land Administration Domain Working Group and ISO Technical Committee 211 (ISO-TC211). There were also ten presentations on country-level land administration initiatives, programmes and efforts to improve security of land and property rights, and efficient and effective land administration services that are people-centric in support of national development priorities. These were followed by presentations outlining regional initiatives and activities that support national implementation for Africa, Latin America and Europe. Then there were the thematic presentations that provided information on issues of legacy data, three-dimensional data (3D Land & Marine) and the proposed initiative on a national tenure atlas.

The second day began with a presentation by the Secretariat that provided additional context about the role and contribution of the Expert Group, and clarified and addressed some issues that were raised in various discussions and deliberations during the first day.

The Expert Group agrees that the overarching focus is to improve tenure security and better land and property rights for all. The indicators are meant to assist in review and follow-up, measure and monitor progress. There was further agreement on the need to advocate policies that i) promote affordable access to basic geospatial datasets, ii) avoid duplication, particularly in mapping (collect once for a multiplicity of purposes and uses), and iii) support data sharing and interoperability. A tenure security atlas should provide and visualise the state of play of tenure security at all levels. The atlas should also support the monitoring of progress of tenure-based Sustainable Development Goals (SDGs).

Christiaan Lemmen

More information
www.fig.net

GSDI Small Grants Program 2017 - Call for Proposals

Participants in the Small Grants programme.

Since its launch in 2003, the GSDI Association's Small Grants Program has supported more than 110 SDI-related projects around the globe. Support for the programme historically comes from a partnership between GSDI Association members such as the U.S. Federal Geographic Data Committee and Canada's GeoConnections Program, and volunteer contributions from the GISCorps of URISA. Three types of award are available: a cash award of up to USD2,500 per project; SDI/GIS consulting services up to the value of USD2,500; or a combination of cash award and SDI/GIS consulting services. The consulting services are offered through the GISCorps volunteers and GSDI members.

The most recent projects from the Call for Proposals in 2015, which completed their work in 2016, included work in Ecuador, Indonesia, Jamaica and South Africa. The Ecuador project focused on getting institutions and organisations interested and involved in constructing the community-based SDI GeoCommunity Galapagos. The Indonesian project developed a comprehensive web-based self-assessment survey of SDI readiness portraying the readiness in SDI development by Indonesian local governments. In Jamaica, the project upgraded the National Metadata Portal for geospatial data. South Africa's Committee for Spatial Information project prepared a framework for South African SDI education and training. These are typical of the range of themes and objectives that are expected from proposals for GSDI Small Grants awards.

Since 2003 when the programme began, nearly a quarter of a million US dollars have been allocated to projects co-funded by the GSDI Association. In 2017, additional funding is made available from the association's own reserves, while additional external support funds are being sought. Those interested in supporting the programme with funding or consulting help are requested to contact the GSDI secretary-general.

Small Grants awards are embedded in the GSDI's Capacity Building Program (2017-2018) which also supports strategic projects such as the Marine SDI Best Practice Project and GI-NSDI – Towards a Global Index of National Spatial Data Infrastructures Project. For more information on the current Call for Proposals for GSDI Small Grants, please contact the GSDI secretary-general, Roger Longhorn, at secgen@gsdi.org. For information on past projects and details for submitting a proposal for the 2017 round of grants, please visit the GSDI website at http://gsdiassociation.org/index.php/projects/small-grants.html.

More information
[1] gsdiassociation.org
[2] opendata.bk.tudelft.nl

Report on the SIRGAS 'Vertical Datum' Workshop

The main objective of the SIRGAS (*Sistema de Referencia Geocéntrico para las Américas*/ Geocentric Reference System for the Americas) Working Group III Workshop was to identify the challenges associated with the unification of vertical networks in the SIRGAS region. This workshop was the latest in the sequence from the SIRGAS School on Vertical Reference Frames in Rio de Janeiro, Brazil, in 2012, and workshops in La Paz, Bolivia, in 2014 and Curitiba, Brazil, in 2015. The latest workshop took place in

Participants at the workshop.

The first part of the workshop defined the foundations and data processing strategies related to vertical reference systems/frames as well as gravity reference systems/frames. The second part was concerned with the analysis of databases and data processing of national vertical network realisation in the geopotential space using geopotential numbers. The basis of data processing was a software package developed by Prof Dr Hermann Drewes and Dr Laura Sánchez, who were also instructors in the workshop. Preliminary analyses of the consistency of national nets were done using a software package developed by Prof Dr Roberto Teixeira Luz, who was also an instructor in the workshop.

Quito, Ecuador, from 21-25 November 2016, with the support of the Military Geographic Institute, Ecuador, the Pan-American Institute of Geography and History (PAIGH) and the International Association of Geodesy (IAG). A total of 44 people from ten countries in South America, Central America and the Caribbean participated.

The workshop was held in the context of the new International Height Reference System (IHRS), its realisation (IHRF) and the Global Geodetic Reference Frame (GGRF) referred to in the United Nations Resolution (A/RES/69/266) on 26 February 2015. The workshop sought to address the following issues:

- Define strategies to realise vertical networks by physical heights [HP =f(CP)]
- Link national vertical networks to the SIRGAS GNSS continuous reference stations
- Integration of national vertical networks of member countries in the geopotential space
- Approaches for referring the SIRGAS Vertical Network to the W0 value of the IHRS
- Decision on a specific epoch by considering the realisation epoch and temporal variations of coordinates
- Planning of activities for establishing a GGRF station profile in the SIRGAS region
- Future link of the SIRGAS Vertical Network to the profile of GGRF stations

Argentina and Uruguay concluded the geopotential differences adjustment of their nodal vertical networks points. Most of the countries have partial or preliminary results. However, there was gain for each country when considering the positive results related to the understanding of problems related to their networks and the increase of their capability in data processing. There is no doubt that the ongoing IAG activities related to the IHRS/GGRF are now of relevance to the SIRGAS community.

Prof Dr Sílvio R.C. de Freitas
Chair of the SIRGAS WG III

More information
http://iag-comm4.gge.unb.ca/

The Washington Fringe (Part 2)

Capitol Building, the home of the United States Congress, Washington DC.

Last month's ICA column for *GIM International* highlighted the range of pre-conference workshops being held in Washington DC prior to the 28th International Cartographic Conference in July this year. This month we continue with the overview of events, most of which are summarised at http://icc2017.org/preconference-workshops/.
On 2 July, there is a short morning workshop offered by the Commission on Map Projections considering standardisation of symbols and nomenclature in map projections, and also discussing the continued use of developable surfaces in map projection theory and preferable alternatives to this approach.

The Commission on Cartography in Early Warning and Crises Management has scheduled a full-day workshop on 2 July, entitled ‘Disaster Management, Big Data, Services and Cartographic Representation’. Organised with support and assistance of the Group of Earth Observations (GEO), the intention is to reflect new challenges coming from United Nations activities, especially following up on the 2015 UN Disaster Risk Management conference in Japan. This workshop will cover topics such as dynamic and real-time cartographic visualisation concepts and applications for enhanced operational early warning (EW); control and automation in the domain of sensor data acquisition for disaster risk reduction (DRR), disaster risk management (DRM) and EW; potentials and applications of novel big data, smart data, volunteered geographic information (VGI) and rapid mapping techniques in DRR; remote sensing usability for DRR; social media – from information to visualisation for action; and web services – use and architecture server-side and client-side for disaster management.

The active Commission on Open Source Geospatial Technologies will meet with the Commission on SDI and Standards to host SDI-Open 2017, covering spatial data infrastructures, standards, open source and open data for geospatial (1-2 July). Spatial data infrastructures aim to make spatial data findable, accessible and usable. Open source software and open data portals help to make this possible. In this workshop, participants will be introduced to SDIs, standards, open source and open data.

An interesting conjunction of the Commissions on Art & Cartography, Cognitive Issues in Geographic Information, and Topographic Mapping will deliver a further two-day workshop titled ‘Maps & Emotions’. This will address the importance of integrating emotions and affects in studying places, and consider the relationships between maps and emotions from two different perspectives – scientific and artistic.

Finally, a more extensive three-day workshop will take place at the Library of Congress from 28-30 June, with three more ICA Commissions (History of Cartography, Toponymy and Atlases) presenting ‘Charting the Cosmos of Cartography: History – Names – Atlases’, with the support of the Library of Congress’ Geography & Map Division.

All these events and the collaboration shown demonstrate the wide range of activities which are being studied and practised by cartographers, and indicate the scope of the discipline. There is much for attendees to experience in these ‘fringe’ activities, and the main conference immediately afterwards (3-8 July) promises further important and interesting engagement with contemporary cartography, mapping and GIS.

More information
www.icaci.org

The Year Ahead for the ISPRS

When the XXIII ISPRS Congress ‘From human history to the future with spatial information’ ended about eight months ago, it marked the beginning of the new ISPRS period: 2016-2020. Since the end of the congress, 36 workshops and conferences, with ISPRS members as either the main organiser (ISPRS-sponsored events) or a co-organiser of the event (ISPRS-co-sponsored events), have been approved by the respective Technical Commission presidents and the secretary general, for 2017 alone! The amount of activity from our members is amazing and I would like to thank all organisers for their huge efforts in organising such meetings, which are the main engine for our society and our branches. An overview of all ISPRS events can be found at http://www.isprs.org/calendar/2017.aspx.

The International Society for Photogrammetry and Remote Sensing (ISPRS) also supports educational events – summer schools, of which three have been approved for 2017. The first one is in May, in Egypt (‘Technology and Summer School on Mobile Mapping’) and the second and third are taking place in July. Austria will host ‘Close Range Sensing Techniques in AlpineTerrain Venue’, and the ‘Summer School on 3D Surveying in Cultural Heritage’ will be held in Italy. All details can be found in the ISPRS calendar.

However, these are not the only scientific ISPRS events for the year. The major meeting of experts and friends of the society in 2017 will be the third ISPRS Geospatial Week (GSW2017), which will be held in Wuhan, China, from 18-22 September 2017. For more details, please visit http://gsw2017.3snews.net. The Geospatial Week is a joint meeting of mainly (but not exclusively) ISPRS workshops, taking place at the same time and in the same location to enable cross-discipline discussion and cooperation. The Geospatial Week is held in odd years between ISPRS Congresses. The organisers of GSW2017 in Wuhan are now very busy as the deadlines for submissions are drawing near. With these deadlines, the start of the following period begins – the reviewing process. Something ends and new things begin. This is (our) life. I hope you enjoy it.

Lena Halounóva
ISPRS secretary general 2016-2020

More information
www.isprs.org

2017

APRIL

GIS-FORUM
Moscow, Russia
from 19-21 April
For more information:
www.gisforum.ru/en

GISTAM 2017
Porto, Portugal
from 27-28 April
For more information:
www.gistam.org

MAY

XPONENTIAL 2017
Dallas, USA
from 8-11 May
For more information:
www.xponential.org/xponential2017

GEO BUSINESS 2017
London, UK
from 23-24 May
For more information:
http://geobusinessshow.com

FIG WORKING WEEK 2017
Helsinki, Finland
from 29 May - 2 June
For more information:
www.fig.net/fig2017

JUNE

HEXAGON LIVE
Las Vegas, USA
from 13-16 June
For more information:
hxgnlive.com/2017

JULY

INTERNATIONAL CARTOGRAPHIC CONFERENCE
Washington, USA
from 2-7 July
For more information:
icc2017.org

ESRI USER CONFERENCE
San Diego, USA
from 10-14 July
For more information:
www.esri.com/events/user-conference

SEPTEMBER

UAV-G 2017
Bonn, Germany
from 4-7 September
For more information:
uavg17.ipb.uni-bonn.de

ISPRS GEOSPATIAL WEEK
Wuhan, China
from 18-22 September
For more information:
zhuanti.3snews.net/2016/ISPRS

INTERGEO
Berlin, Germany
from 26-28 September
for more information:
www.intergeo.de

CALENDAR NOTICES

Please send notices at least 3 months before the event date to: Trea Fledderus, marketing assistant, email: trea.fledderus@geomares.nl

For extended information on the shows mentioned on this page, see our website: www.gim-international.com.

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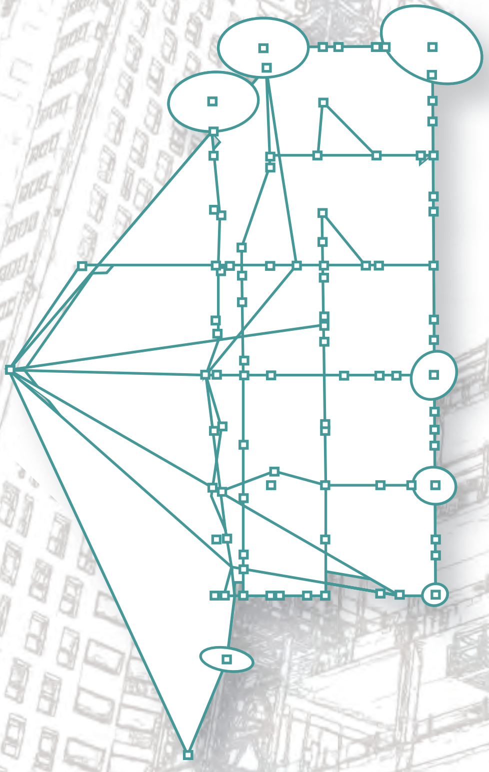

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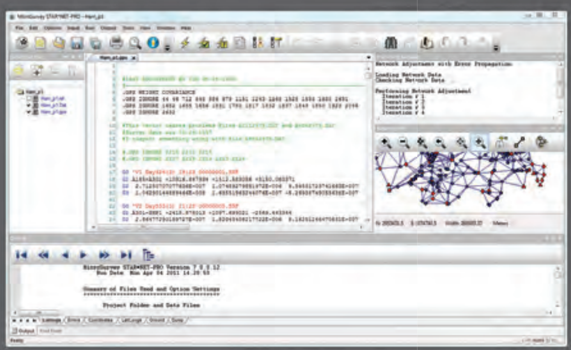

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