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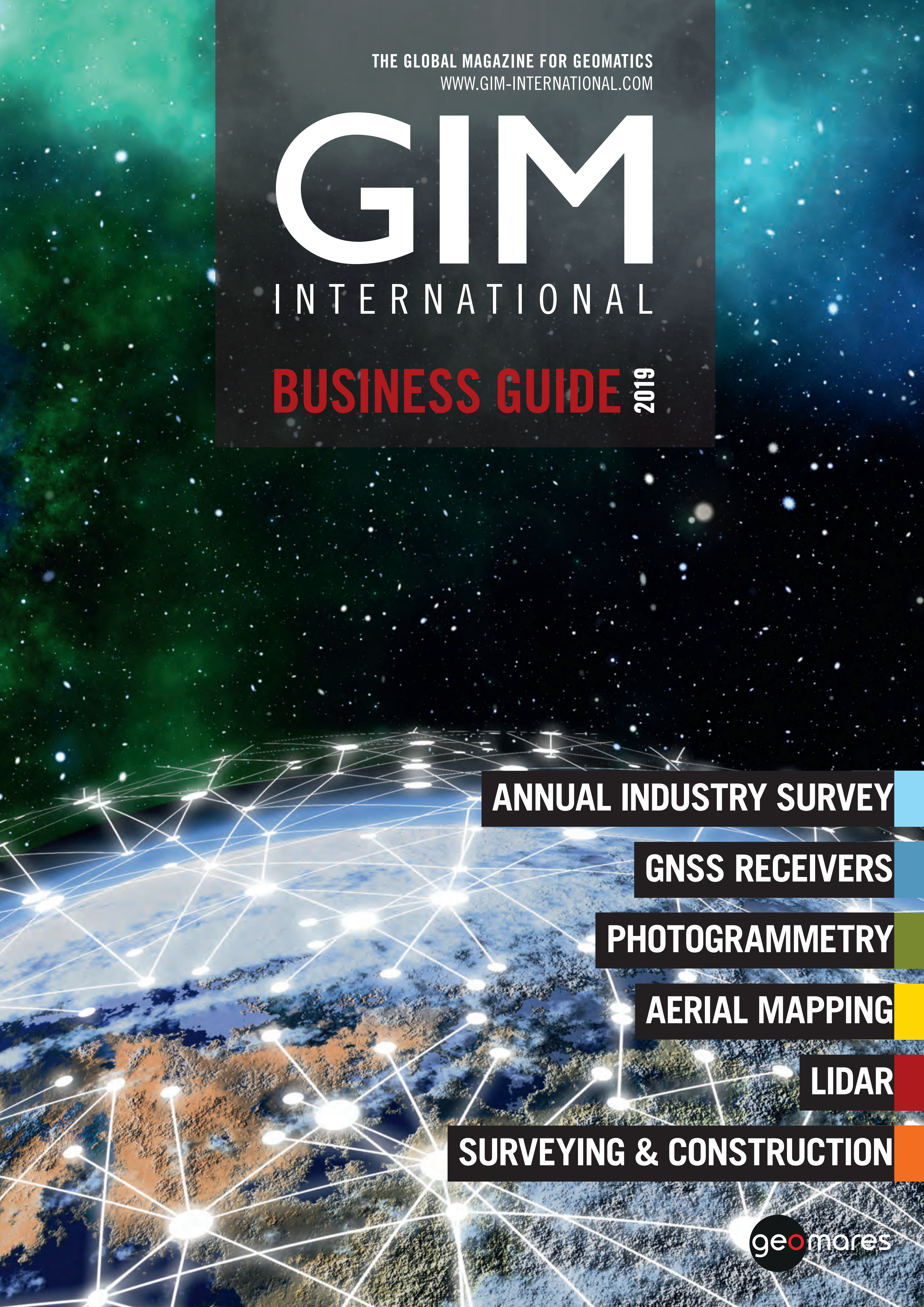
GIM INTERNATIONAL

BUSINESS GUIDE 2019



- ANNUAL INDUSTRY SURVEY
- GNSS RECEIVERS
- PHOTOGRAMMETRY
- AERIAL MAPPING
- LIDAR
- SURVEYING & CONSTRUCTION

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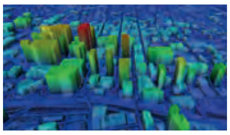
With so many hardware and software solutions for so many professionals in so many vertical markets, there must be a wide variety of user needs – but what parallels can be drawn between those various needs across the geomatics workflow as a whole? At *GIM International*, we investigated this thoroughly by analysing the results of our annual readers' survey.



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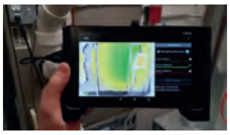
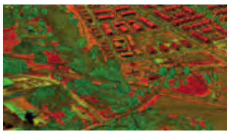
Modern approaches are now being combined with classical photogrammetric methods. Consequently, automatic and autonomous imaging systems are evolving into accurate measuring systems that are useful for professional photogrammetric and geodetic applications. This article addresses these and other recent developments in close-range photogrammetry.



P. 20 Technologies for the Future: A Lidar Overview
Point clouds can be captured by an ever-increasing number of means to understand the surrounding reality and detect critical developments. Diverse applications of Lidar are changing the way we collect and refine topographic data. Which technologies and processes are building the capability for high-density 3D data? This article outlines the latest industry developments.



P. 28 The Relevance of Aerial Mapping in 2019 and Beyond
Reality 3D models, Lidar points clouds, superhigh-resolution aerial imagery and artificial intelligence from aerial imagery… these are just a few of the products derived from aerial mapping that the GIS sector takes for granted in 2019. This article takes a brief look at the latest aerial mapping systems and processes, along with the ever-expanding range of products and services derived from such systems.

P. 33 The Rising Demand for Total Stations and Terrestrial Laser Scanners
Geomares has analysed the user data and behaviour of thousands of members of the global geospatial community. It is interesting to see how the market of 'traditional survey equipment' such as total stations and terrestrial laser scanners will respond to the growing construction market and the digitalization of this area.

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Working Together

The geospatial industry is a small, often friendly and open industry. Exhibitions, conferences and other events are a showcase for cooperation, networking and finding synergy. I don't deny there is a competitive atmosphere, but it is healthy and often based on opportunities for collaboration. The outlook for the industry is largely optimistic, with the strongly growing need for geoinformation having a positive impact on the amount of orders in the pipeline. On the other hand, the newspapers are full of more pessimistic news about the economy these days. The overall sentiment is not a good one. A full-blown trade war between the US and China and a hard Brexit are just two horror scenarios that we could face in 2019. The economic powerhouses of the world are decreasing their production, growth is slowing down. Just as we are finally starting to recover from the crisis that began in 2008, economists are now warning that some economies could dip into recession again. Part of the problem is self-inflicted. Institutions, countries, companies and citizens – all the factors making up an economy – thrive on cooperation. Even competition flourishes in open markets created by trade agreements between governments. Closing down markets, no longer working together, halts growth. With this in mind, it is applaudable that working together has always been the mantra in our 'little' yet very internationally linked geospatial industry – and this collaborative trend continues to grow, supported by the learned societies, international companies and intergovernmental cooperation, as demonstrated by the United Nations Global Geospatial Information Management (UN-GGIM) initiative. If we maintain that spirit and intensify our cooperation, working together where possible and competing to make our products even better for the end users, we should not only be able to withstand the harsher trends but hopefully even grow! This *GIM International* Business Guide provides a roundup of what is happening in the entrepreneurial part of our industry and includes shining examples of global cooperation, healthy competition and international partnerships focused on integral growth for the benefit of customers – and society as a whole – in 2019 and beyond!

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Reference Book

Throughout the year, at *GIM International* we strive to bring you the latest trends and developments in the geospatial industry. This is part of our mission to keep you up to date through our magazine, website, newsletter and social media channels. In-depth articles, case studies, interviews, columns and news stories are all good ways to provide you with need-to-know (and sometimes also nice-to-know) information. On top of this, once a year we publish the Business Guide, which serves as a reference book for geomatics professionals. This year's edition contains an overview of various pillars of the mapping and surveying industry.

The Business Guide is also the ideal occasion to unveil the findings derived from our annual readers' survey. This year, the report on these findings focuses on the current status of the broad range of disciplines that together form geomatics. It makes for uplifting reading, as there are plenty of reasons for optimism in our industry; many of the respondents signal a wealth of growth opportunities for geospatial surveying. The market analysis contributed by Peter Tapken from *Geo-matching* reinforces this view. His article shows how suppliers of 'traditional survey equipment', i.e. total stations and terrestrial laser scanners, could capitalize on the growth of the construction market and the digitalization of this area. Tapken's analysis mainly focuses on the growing construction sector worldwide – where indeed the digital transformation presents great opportunities for the geospatial sector – but there are definitely other application areas offering huge potential for mapping and surveying experts too.

So this Business Guide is a reference book, containing background articles on GNSS receivers, (close-range) photogrammetry, Lidar and aerial mapping. As every year, some of the leading companies in the geospatial industry are presented in a series of a company profiles which you will find throughout this guide. Last but not least, the exciting topics of 5G and BIM are highlighted by two columns. I hope you enjoy this year's edition. Feedback is always welcome, as are ideas and suggestions for new articles. Feel free to share your thoughts – either when we meet in person at an industry event, or otherwise by phone, e-mail, LinkedIn or Twitter. I look forward to hearing from you!

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UNVEILING THE FINDINGS FROM GIM INTERNATIONAL'S ANNUAL INDUSTRY SURVEY

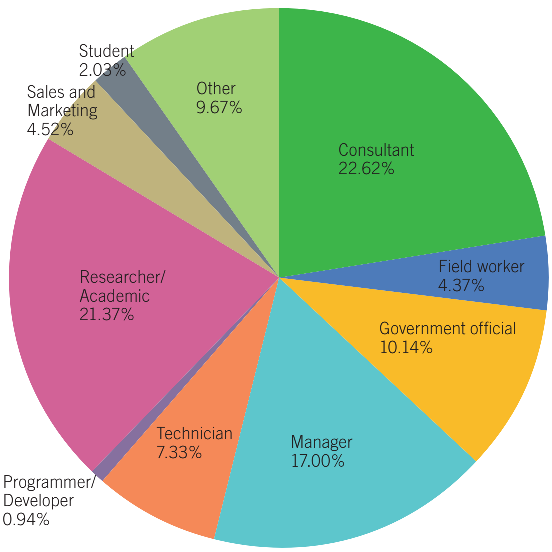
Thriving Geospatial Market Thanks to **Huge Need for 3D Data**

Many providers of mapping and surveying solutions divide their potential customer base into vertical markets. Producers of GNSS receivers are targeting their products at professionals in agriculture, construction, surveying, mining and forestry, for example. The Lidar industry focuses on fields of applications including archaeology, corridor mapping and civil engineering as well as mining and – obviously – surveying. With so many hardware and software solutions for so many professionals in so many vertical markets, there must be a wide variety of user needs – but what parallels can be drawn between those various needs across the geomatics workflow as a whole? At *GIM International*, we investigated this thoroughly by analysing the results of our annual readers' survey.

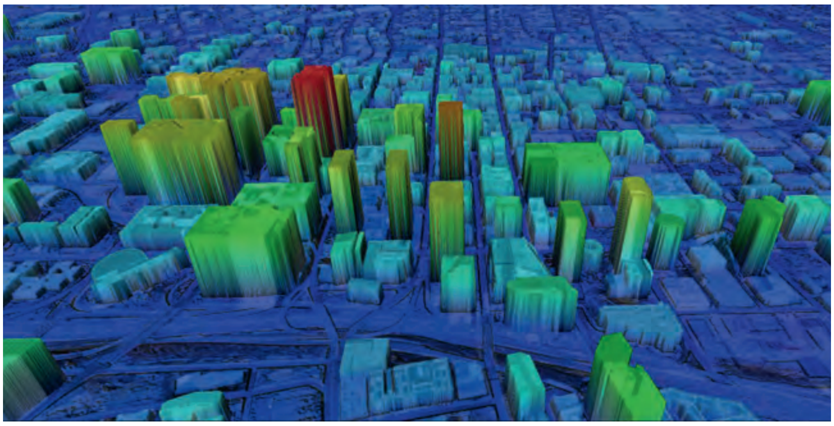
The term 'geomatics' encompasses a broad range of disciplines, including photogrammetry, remote sensing, land surveying, GIS and GNSS, as well as areas of experience such as Lidar, location-based services, cartography and image processing. But where are these disciplines used? In other words, in which sectors are our survey participants active? Most of the respondents (68.9%) indicate they are involved in land surveying, followed at a considerable distance by land management (32.5%), infrastructure (27.7%), building & construction (26.9%) and urban planning (24.1%). It is fair to say, however, that there is a degree of overlap between land surveying and the other areas.

CLASSIFYING GEOMATICS PROFESSIONALS

Let's dive a bit deeper to find out more about the geospatial professionals who participated in our survey. Who are they exactly? We asked them what best described their job title. 22.7% chose consultant as their answer, closely followed by researcher/academic (21.4%), with manager (17.6%) completing the top three (Figure 1).



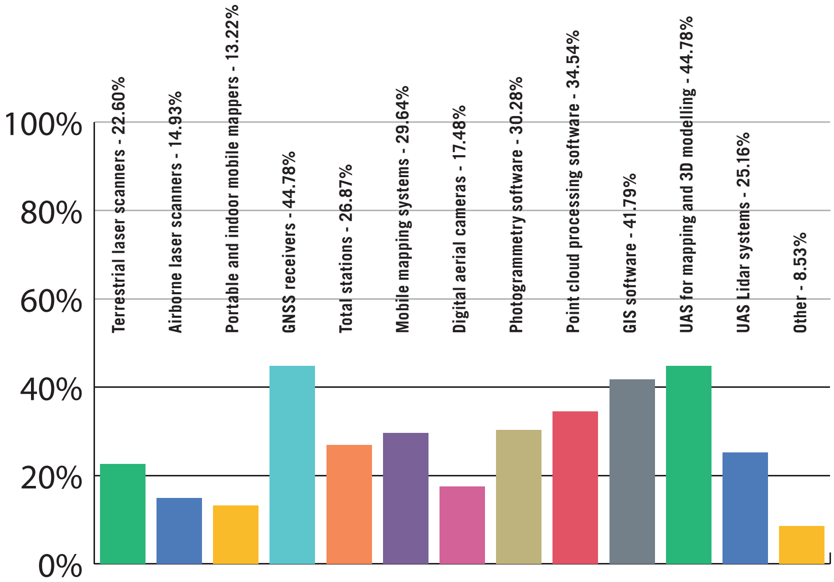
▲ *Figure 1: Geospatial professionals categorized by job title.*



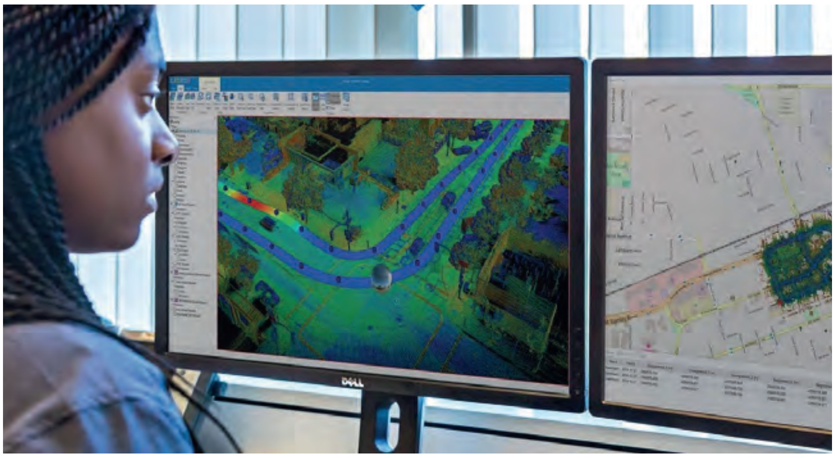
▲ *Figure 2: The rapidly expanding need for 3D geodata represents bright perspectives for the geospatial industry. This image shows NEXTMap One terrain dataset – Intermap's solution for high-precision, 3D geospatial data at 1m resolution anywhere in the world.*

Geomatics consultants can be defined as mapping and surveying experts providing the full spectrum of surveying, monitoring, 3D modelling and imaging services to a wide-ranging client base. Many surveyors are working for consulting firms. AAM Group, COWI, Fugro and Woolpert are just a few well-known examples of consultancy companies that provide accurate and comprehensive surveying, mapping, geomatics engineering and 3D analysis services for civil engineering infrastructure and other projects.

The geospatial professionals working as researchers or academics are often employed at universities in the civil engineering (or similar) department or faculty, where they are involved in geomatics-related research and education. It is also worth mentioning the notably high representation among our survey respondents of geospatial professionals working as government officials.



▲ *Figure 3: 45% of the survey participants indicate that their organization is planning to invest in a UAS.*



▲ *Figure 4: The future looks bright for manufacturers of point cloud processing software. (Courtesy: Topcon)*

OPTIMISTIC OUTLOOK FOR GEOSPATIAL INDUSTRY

In addition to gaining insight into the industry demographics, *GIM International's* annual survey is also a good opportunity to measure the general business mood. We asked geospatial professionals about their expectations regarding the prospects in the surveying market in 2019 in comparison with the last three years. The outcome was very similar to last year's poll: about 19% expect a much better business environment, while roughly 48% foresee some improvements. 26% expect the market situation to remain stable.

So the overall vibe is positive and optimistic, with the most promising perspectives stemming from the lively construction and infrastructure sector. This is especially the case in the likes of China, India and the Middle East, where numerous vast and prestigious projects for new cities, highways and railways are in full swing – with even more in the planning and development phase. Hence, the prospects look particularly good for companies involved in construction and engineering. However, it should be pointed out that there are some potential constraints. These are not unique to the geospatial industry; the widespread optimism in the surveying market is most at risk from geopolitical developments. International relations, the worldwide political order and potentially disruptive events can all have an impact on the global economic situation. How will Brexit play out, and how will it affect the economies of the European Union as well as the UK itself? Other regions to watch are the Middle East (will stability increase?), the USA (how will the economy develop?) and China (what will happen to the economic growth curve?). And on a global scale: will import tariffs and other protectionist measures become the new trend, or will the governments of the main economic powers scale back their intervention in the worldwide economy? All of these factors will have a direct influence on the geospatial industry.

DEFINING GROWTH OPPORTUNITIES IN GEOMATICS

We asked our readers where they see growth opportunities for surveying in their current sector. This was an open-ended question, and close analysis of the answers reveals several interesting points. The most frequently mentioned sectors that offer growth potential for surveyors include land management, construction, infrastructure, urban planning and smart city projects. The application of unmanned aerial vehicles (UAVs or 'drones') for mapping and surveying projects in all kinds of areas is another clear growth opportunity, according to the survey. One of the key pillars underpinning the widespread positivity among geomatics experts is the rapidly expanding need for 3D geodata, driven by the huge – and ever-growing – interest in the construction of 3D models of urban and built environments. This is obviously directly related to the countless large infrastructure and construction projects that are under way all around the globe. As one of the survey participants very aptly describes: "Entire cities all over the world will get their digital twin, and location will be the key for combining all sorts of data". Indeed, geospatial data is the backbone of the digital replica of cities. This burgeoning demand for 3D geodata offers a wealth of new opportunities, in response to which ▶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many companies in the geospatial industry are heavily involved in innovating new digital mapping and rendering techniques (Figure 3). As illustrated by the vertical division of the customer base to focus on distinct fields of application, more and more companies are developing ever-more advanced geospatial tools to represent the 3D world in line with specific application-related needs.

THE NEED FOR NEW MAPPING SOLUTIONS

Last year, an astonishing 70% of the survey participants revealed that their organization was planning to invest in new systems. This figure has fallen slightly this year, but still shows a very positive outlook for manufacturers and developers of mapping and surveying solutions, with almost two-thirds of organizations intending to purchase new equipment and software – but which types of systems? UAVs are the clear winner: 45% of the geospatial organizations plan to invest in an unmanned aerial system (UAS) for mapping and 3D modelling, while a further 25% have plans to acquire a UAS-Lidar system. So the future looks bright for drone companies involved in the mapping and surveying field.

The drone has overwhelmingly succeeded in its mission to acquire a permanent place in the surveyor's toolkit. The 2019 *GIM International* survey clearly indicates that the UAS has become an important instrument in the geospatial industry, just like total stations, GNSS receivers and – in various guises – laser scanners. In light of this, perhaps the time has come to wonder why there are so many trade shows focused on UAVs. Imagine if professional surveyors were expected to attend events that only showcased the latest total stations, or that geobusiness delegates would visit an exhibition solely dedicated to terrestrial laser scanners…

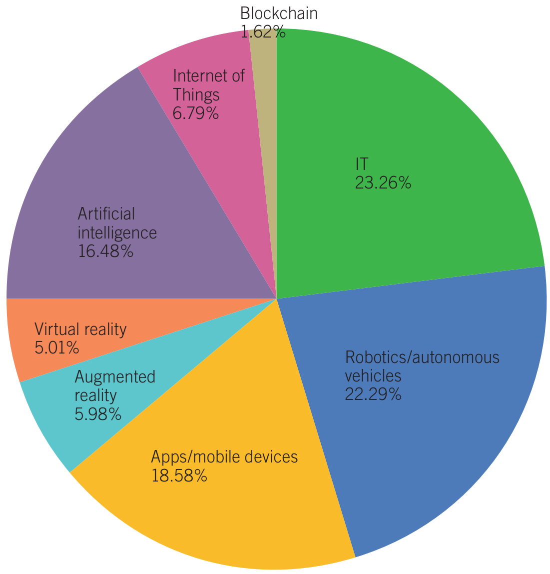
GNSS receivers remain crucial for surveyors as core devices for satellite positioning. Almost 45% of our respondents state that their organization is planning to spend money on such devices. As the workload for surveying professionals is likely to increase, the demand for GNSS receivers is obvious. There are so many different applications for GNSS receivers that we cannot list them all here, but the fields in which surveyors are involved in the geomatics industry (as outlined above) give a good general indication of their usage.

On the software side, about 35% plan to invest in point cloud processing software, closely followed by photogrammetry software – 30% of the organizations intend to obtain new photogrammetry software (Figure 4). In a previous *GIM International* survey, we asked geoprofessionals what they valued most about their chosen geodata acquisition method. Interestingly for providers of photogrammetric solutions, high accuracy topped the list of priorities (scoring more than 65%). This was closely followed by spatial resolution/point density (just over 50%). Processing software reliability came third with 33%, followed by aspects such as rapid availability of final products and a well-established workflow. These findings are echoed by the respondents in our latest survey.

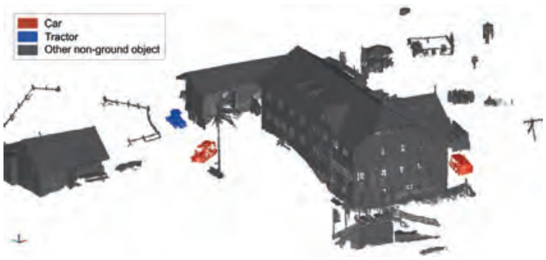
THE IMPACT OF NEW TECHNOLOGY ON SURVEYING

At *GIM International* we strive to report on the state-of-the-art mapping and surveying solutions utilized by experts all over the world, so our annual survey is also an excellent opportunity to ask our highly valued audience which technology they believe is currently having the greatest impact on the surveying profession. In this case, instead of a 'top three' we have ended up with a 'top four': IT, robotics/autonomous vehicles, apps/mobile devices, and artificial intelligence (AI) are all regarded as technologies that will have a major impact on the geospatial business (Figure 5).

At the same time, it is also interesting to learn which trends our respondents foresee over the next five years. This will hopefully inspire suppliers of innovative mapping and surveying solutions to continue pursuing their R&D efforts that are set to change the professional surveying environment. In response, various 'hot topics' are mentioned, such as the integration of GIS and BIM, the increasing role of AI into geomatics (Figure 6), and the integration of systems and interoperability, but we also received some more future-oriented comments, many of which referred to the digital transformation. There is no doubt that digitalization is having an extremely disruptive impact, but is this also an advancement in every sense? One of the survey respondents sums up the sense of loss of 'times gone by' as follows: "I guess all these IT solutions will be the most important trend in the future, with less and less emphasis placed on traditional survey methods. Unfortunately, with this development, intuitive methods are slowly taken away…". At *GIM International* we trust that the established companies as well as the 'new kids on the block' will help to prevent us from becoming too nostalgic. Ultimately, the adoption of high-end geospatial technology in many applications in wider society will open up a lot of new opportunities for tomorrow's surveyors. This may make their work a little different from that of traditional surveyors, but probably no less exciting.



▲ *Figure 5: IT, robotics/autonomous vehicles, apps/mobile devices and AI are considered the four key technologies of the future.*



▲ *Figure 6: Simple example of AI: Object-based classification of vehicles in a point cloud acquired by a Lidar-equipped UAS.*

ABOUT THE AUTHOR

Wim van Wegen is content manager of *GIM International*. In his role, he is responsible for the publications of one of the world's leading geomatics trade media brands. He is also a frequent contributor of columns and feature articles, and often interviews renowned experts in the geospatial industry.
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PAST, PRESENT AND FUTURE OF POSITIONING

GNSS Receivers – Evolution or Revolution?

Satellite surveying… are there any industry professionals out there not using it on (almost) a daily basis? Over the last 30 years, GNSS has become the main positioning instrument for most applications. Of course, there are still some exceptions where correct (relative) positioning is needed and dedicated optical systems such as a total station or level instrument are used, but even these are often set up over control points determined using GNSS techniques. This article investigates the developments in GNSS over the last decade and attempts to predict the future.

Around a decade ago, a review of GNSS systems would have entailed two types of systems. The most prevalent was the high-end RTK unit costing over €20,000, and the second type was the handheld GIS data collector. The main difference between them was their accuracy – centimetre versus (deci)metre level – and their antenna. The high-end systems all had a large antenna with an integrated receiver and separate controller that you had to mount on your survey pole, whereas the GIS types had a (small) patch antenna, receiver and controller integrated into a single unit. The only other type of system one could have were the machine control units for the construction industry; these were based on the same technology as the high-end RTK units.

APPLICATIONS

All the above instruments are still used today. The high-end RTK system still looks the same but has come down in price. And, where the standard setup in the past would be two units connected by UHF radio, most brands now offer that just as a choice. The main connectivity comes from mobile data networks with corrections sent over the internet. Rather than supplying a similar unit as a base station, most manufacturers now offer what they call a network receiver capable of transmitting (and receiving) network corrections (Figure 1).

Another major development in GNSS receivers over the last few years is the integration of an 'electronic' bubble in the pole (Figure 2). Whereas in the past the pole had to be kept exactly upright for a correct position (and height) measurement, the modern receiver now has an integrated roll and pitch sensor like those in a smartphone. Using the readings from the sensor (and the antenna height), the position of the antenna is corrected towards the ground point up to an angle of 30 degrees. Based on this additional information it is possible to hold the pole at an angle and still obtain the correct position and height information. This not only makes accurate measurements easier; it also

Figure 1: Networked continuously operating reference station (CORS) (Satlab).

Figure 2: Tilt-enabled high-end land survey RTK receiver (ComNavTech).

Figure 3: Bluetooth receiver for mobile device connection – Note: Apple devices not to scale (SxBlue GPS).

allows the surveyor to measure otherwise inaccessible points by positioning the pole at an angle.

Taking the use of freely available satellite-based augmentation system (SBAS) corrections and post-processing of earlier GIS data collectors a step further, this type of receiver is nowadays capable of receiving RTK corrections as standard, thus allowing the collection of GIS data to centimetre level rather than metre level. Also, GIS receivers increasingly no longer have an integrated controller but rely on any Bluetooth connected device such as an Android smartphone instead (Figure 3).

In addition to the receivers mentioned above, there are a multitude of small black-box RTK receivers designed specifically for use on unmanned aerial vehicles (UAVs or 'drones') or for machine control (Figure 4). Often these have a large integrated memory allowing them to (also) store raw data for post-processing, giving even more accurate positions.

GNSS CONSTELLATIONS

About ten years ago, GNSS life was simple for the end user: it was pretty much GPS or nothing. Glonass, the Russian GPS equivalent (and the first to reach operational capability in the early 1990s), had deteriorated due to the economic crisis at the end of the 1990s. Glonass was revived a few years later, getting back to full operation about five years ago.

At the same time, although we all used GPS, another system was becoming 'the talk of the town': Europe's Galileo. Set up as a public-private partnership in the early 21st century, it was reshaped into a government-only (but still civilian) system. Although Galileo is not expected to reach full operational capability until sometime in 2020, the reception of Galileo signals already benefits positioning quality.

Last but not least, seemingly out of nowhere, has come BeiDou, the Chinese GNSS. It was initially set up as a regional system, but the Chinese were quick to start launching satellites. With 23 satellites in orbit (of which a considerable number are indeed regional), there is now full capability over central Asia and initial capability in the rest of the world. In other words, for those using their receivers in central Asia it is worthwhile to ensure that their system also has BeiDou reception.

SYSTEM DEVELOPMENTS

But it is not just the number of satellite systems that have increased from 1.5 GNSS to over four GNSSs in the last ten years; developments within the systems have also taken place. On 24 December 2018, almost five years after the original plan, the first GPS-III satellite capable of new (and more accurate) positioning signals was launched. In 2020, the first launch of Glonass satellites with a full range of so-called CDMA signals is expected to bring the system onto the same signal basis as the other GNSS.

Whereas ten years ago a receiver with 80 channels would have been considered technologically advanced, a modern receiver needs over 500 channels in order to optimally support all the signals from the four current GNSSs (Figure 5). After all, a single signal from a single frequency on a single satellite in a single GNSS accounts for a single channel in a GNSS receiver, and each GNSS has between 25 and 30 satellites in space, each broadcasting two to three signals on around three frequencies.

CORRECTION SIGNALS AND ACCURACY

Merely receiving signals from the four GNSSs does not give the professional user the required accuracy. Standard positioning from any of the four GNSSs alone (or combined) is at the metre level. However, for any modern job sub-metre accuracy is a common requirement. To achieve this higher accuracy, correction signals are needed. The most usual types of correction signals are the free-to-air SBAS such as the American WAAS or the European EGNOS. These signals, which are broadcast in many parts of the world from the various SBAS systems, can be received by all GNSS receivers, whether they are professional ones or inside a smartphone. SBAS corrections make it possible to achieve an accuracy of around one metre.

For those needing better accuracy, the standard correction signal to go to is real-time kinematic (RTK dGNSS or RTK). As a standard, all professional RTK receivers

Figure 4: Miniaturized RTK receiver for UAV use (Tersus-GNSS).

can run RTK GPS whilst most of them also support RTK Glonass corrections. No receivers currently offer more than joint GPS and Glonass RTK solutions, but manufacturers are looking into the addition of Beidou besides GPS and Glonass in the RTK solution. But even with 'just' two GNSS constellations being used in the RTK solution, the current accuracy is less than 1cm + 1ppm (68%) horizontal and 1.5cm + 1ppm (68%) vertical for most RTK-capable receivers. And with the modern network-type RTK, the 15km range limit of the early days with a single base RTK, has been replaced by the requirement to be within the virtual network and have internet connectivity.

The use of precise point positioning (PPP) is new to the land survey industry but has been common in the offshore surveying community for many years. With this technology, accuracies horizontal and vertical of sub-decimetre to the decimetre level are achievable at considerable distances from the base stations. Rather than SBAS and RTK (where the base stations are used for computing differential corrections), in PPP the base stations are used to find accurate corrections to the raw satellite position information. The roving receiver uses this information to compute an improved position, giving a first 'convergence' time of around 20 minutes. As the PPP correction signals are proprietary, not all receivers can use PPP correction signals (Figure 6). All PPP solution providers provide GPS corrections and some also work with a combination of the other available GNSSs.

ANTI-JAMMING AND ANTI-SPOOFING

Whereas a decade ago GNSS was a mainly a professional tool, apart from perhaps being an expensive consumer accessory for in-vehicle navigation, it is now integrated into many applications – principally as a positioning system but also as an accurate basis for timing. With 'autonomous' being the buzzword in the navigation industry, the reliance on both accurate and reliable positioning is increasing by the day. Where reliable positioning is needed, the challenge is not only to tackle weak satellite or correction reception, but also to avoid interference. After all, in view of the rising number of autonomous cars, drones and even ships, a GNSS outage anywhere could quickly lead to all sorts of potentially serious issues. It is relatively easy to 'jam' GNSS signals (causing loss of signal) because the signals are weak. This is not always intentional. A few years ago, a legal argument was fought out in the USA between LightSquared and the American GPS community over LightSquared's proposed transmission network due to its interference risk. This illustrates the concern about GPS jamming. In the end LightSquared went bankrupt (and was recently refloated as Ligado with a GPS-friendly solution). Even

Figure 5: Modern receiver capable of receiving 572 channels (Geo-Fennel).

Figure 6: Mobile receiver capable of PPP positioning using Atlas corrections (Hemisphere GNSS).

more potentially dangerous is what is known as 'spoofing', in which the original signal is intentionally replaced by a stronger incorrect signal. Tests have shown that if this is done subtly, many receivers and applications will start to follow the incorrect signals, which could ultimately cause ships or aircraft to collide or military troops to be directed off course. To counteract these effects, industry-leading manufacturers such as NovAtel are not only researching anti-jamming and anti-spoofing solutions but are also introducing new antennas that are more resistant to jamming (Figure 7).

INTO THE FUTURE

Technology has clearly progressed over the past ten years. The main change has been from just one fully operational GNSS (i.e. GPS) towards four (almost) fully operational systems today. But other improvements have also been made. As a result, we will see receivers with more channels appearing in the market. For the next decade no radical changes are foreseen. The greatest change will be that of Glonass moving from the current FDMA signal structure to a CDMA structure interoperable with the other GNSSs.

On the technical side, receivers have changed too and – even more importantly – accuracy has been improved across the board, with RTK becoming the standard. Over the next decade we will see new systems bridging the gap between RTK and PPP allowing sub-decimetre-level positioning anywhere in the world and reducing initialization times from the current 20 minutes to a couple of minutes for the first start and to mere seconds after a loss of signal. One of the other changes that is hoped for is the introduction of the Galileo Commercial Service, not only as a free-of-charge PPP alternative but, perhaps more importantly, as a standard to facilitate interoperability of the current PPP solution providers' PPP signals with any GNSS receiver. Lastly, we will see anti-jamming and anti-spoofing solutions becoming more available, with price levels coming down to the current levels of 'standard' equipment.

Figure 7: Anti-jamming GPS L1 and L2 antenna (NovAtel).

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A MEASUREMENT TECHNOLOGY IN TRANSITION

Recent Developments in **Close-range Photogrammetry**

Dramatic advances in automatic digital image analysis have opened up new applications and made photogrammetry applicable for a broader field of users that lack specific knowledge of photogrammetry. Megatrends such as Industry 4.0, building information modelling (BIM) and the digital transformation are driving the advancement of 3D measurement technologies, both in terms of high-end systems and low-cost sensors. New technical challenges such as autonomous driving or unmanned aerial vehicles are demanding innovative sensor systems, but also extended maps and models of the environment. Modern approaches such as structure from motion (SfM), simultaneous localization and mapping (SLAM) or visual odometry are now being combined with classical photogrammetric methods. Consequently, automatic and autonomous imaging systems are evolving into accurate measuring systems that are useful for professional photogrammetric and geodetic applications. This article addresses these and other recent developments in close-range photogrammetry.

New technical challenges such as autonomous driving or unmanned aerial vehicles (UAVs or 'drones') are demanding innovative (hybrid) sensor systems, There is a huge range of image-recording devices available for close-range photogrammetry purposes (see Figure 1 for a few examples). Typical sensors can be roughly classified as follows:

- Action and fisheye cameras
- Cameras for the consumer market
- Cameras for professional applications
- Industrial cameras
- Metric cameras for explicit photogrammetric applications
- High-speed cameras
- Panoramic cameras
- Multi-camera systems

▲ a) Professional DSLR camera Nikon D3, 5,568 x 3,712 pixels.

▲ b) Action camera GoPro Hero7, 3,840 x 2,160 pixels.

▲ c) Metric camera for photogrammetric use GSI INCA 4, 4,096 x 3,072 pixels.

▲ d) High-speed camera pco.dimax, 1,920 x 1,080 pixels >1,000 frames/s.

▲ e) Panoramic camera (Spheron), approx. 50,000 x 10,200 pixels.

▲ f) Stereo camera system AXIOS 3D CamBar.

▲ *Figure 1: A selection of photogrammetric recording systems.*

Practically all modern imaging sensors are designed based on CMOS technology. Their availability ranges from mass products, e.g. smartphone cameras (usually with a rolling shutter), to specific high-performance sensors used for special applications such as high-speed imaging. Sensors with a global shutter are required for most dynamic applications where the camera or object are moving with respect to each other.

HYBRID SENSOR SYSTEMS

An increasing number of hybrid systems are available in which camera sensors are combined with additional measuring devices. The most popular examples are terrestrial laser scanners equipped with one or more cameras for the acquisition of panorama images or for recording colour values for each point of a laser scan. As an example, the Leica BLK 360 scanner (Figure 2a) consists of an additional thermal camera that can measure temperatures. The new Leica RTC 360 scanner (Figure. 2b) consists of five cameras that are used for visual odometry in a SLAM approach in order to measure the way and pose when the scanner is moved to the next station. Other examples of hybrid systems are low-cost sensors running on tablets or mobile devices that combine IMU, GNSS, time-of-flight (ToF), laser triangulation or RGB cameras for low-to-medium-accuracy 3D scanning. Figure 2c shows a handheld tablet device based on a ToF sensor.

a) Terrestrial laser scanner Leica BLK 360, 1 RGB camera, 1 thermal camera

b) Terrestrial laser scanner Leica RTC 360. 1 RGB camera, 5 b/w cameras.

c) Tablet with the DPI-8 3D sensor (DotProduct).

Figure 2: Hybrid recording systems.

CAMERA CALIBRATION

Almost every kind of camera can be used for photogrammetry as long as the interior orientation (camera parameters) can be calibrated. In particular, the functional model for modelling lens distortion and other imaging errors must be chosen appropriately to the specific camera. Depending on the stability and reproducibility of the camera geometry, it can be calibrated prior to or after a measurement if there is no ability for self-calibration on the job. Examples are measuring systems with a fixed arrangement of cameras in a housing. Examples of highly stable metric cameras are given in Figure. 1c and Figure 1f. Artificial test fields are usually applied here for pre-calibration which should have a three-dimensional distribution of targets to provide a reliable and full calibration of the camera with minimum correlations to exterior orientations. For a large number of applications, the camera can be calibrated simultaneously with 3D object reconstruction by bundle adjustment. In this case, the camera is calibrated for the time of object recording, hence without any assumption of validity of previous calibration parameters. This approach is included in standard photogrammetric offline systems, e.g. SfM.

MEASUREMENT OF TIE POINTS

Multi-image photogrammetry requires overlapping images which are connected by corresponding points (homologous or tie points). By means of targets, which may be coded to define a certain point number, the process of finding correspondences and approximations for orientation is relatively easy. Using natural features as tie points, certain detectors and descriptors allow for the matching of similar features using different criteria. As examples, operators like SIFT, SURF or ORB provide robust feature detection and matching. However, for a reliable match it is recommended to acquire the images with a large relative overlap, e.g. 90% from image to image. Matching becomes weak or even impossible if large object areas are imaged without sufficient textures.

ORIENTATION

The calculation of the exterior orientations of all images (also called alignment) is a prerequisite for subsequent 3D object reconstruction. Basically, the process starts with a complex procedure for finding approximate values of all unknown parameters by a clever combination of relative and absolute orientations, space resections and intersections. The final optimization of all parameters is done by bundle adjustment which minimizes the residuals of all observations (image measurements) in one process in order to determine the desired calibration and orientation parameters, and the 3D coordinates of all tie points. If control points are available, they are integrated to define the final coordinate system and to compensate for the datum defect of a photogrammetric network. The 3D coordinates of all measured points provide a sparse point cloud of the object surface.

Bundle adjustment is the critical part in a photogrammetric orientation process. Hence, statistical quality parameters (sigma values, RMS of object points) shall be analysed carefully to provide a picture of the internal precision of the adjustment. However, the real accuracy must be checked by independent reference values (see below).

SFM AND SLAM

Basically, the structure-from-motion approach is a complex procedure where subsequent images with high overlap are oriented automatically by means of feature detection, feature matching and robust sequential orientation. Based on RANSAC-based procedures and linear estimation models, datasets with a high number of outliers can be processed sufficiently.

Simultaneous localization and mapping (SLAM) approaches are often used in dynamic environments (e.g. moving robots) to measure the route (pose) of the sensor and the unknown environment simultaneously. Image-based SLAM algorithms are also called 'visual odometry'. Since the geometric configuration of image sequences is often weak, additional sensors (e.g. IMU) and Kalman filtering are included.

DENSE POINT CLOUDS

After successful bundle adjustment, a dense point cloud of the object surface can be calculated, if necessary. The objective is to derive 3D coordinates for every pixel (or in a specific resolution in object space). Today, the most successful approaches are based on semi-global matching (SGM) which looks for best matches along epipolar lines by minimizing a particular cost function. SGM is a robust method that can interpolate textureless areas and create surface models that sufficiently preserve sharp edges in object space. Compared to the orientation process above, the generation of dense point clouds requires much higher computational effort.

ORTHOPHOTOS

Even in close-range photogrammetry, the generation of (true) orthophotos has become an important product, especially for UAV applications or in architectural and archaeological projects. Since the process described above generates orientation parameters and a dense surface model, orthophotos can be derived directly from the acquired images. However, a photogrammetric point cloud usually describes the visible surface of the object, i.e. with vegetation or other disturbing objects included. Before a final true orthophoto can be produced, the surface model may be subject to (manual) cleaning, filtering or other types of post-processing.

3D MODELLING

In many applications, further processing of point clouds is required, e.g. for the production of architectural plans or 3D models for BIM or facility management. Although a number of semi-automated software approaches are available for the extraction of certain elements (e.g. planes, pipes), the generation of final products often requires manual processing. This holds true for any kind of point clouds, i.e. also from laser scanning or other technologies.

Semantic modelling, i.e. automatic classification of object parts, is still an ongoing research task that must involve human knowledge of the object and the application. Recent machine learning approaches demonstrate promising solutions to solve at least a part of the modelling interpretation process.

ACCURACY AND VERIFICATION

Professional use of photogrammetry usually involves specifications for high-quality results. In industrial applications, the verification of the achieved accuracy with respect to accepted guidelines is most important. In most cases, standardized characteristics such as the maximum length measurement error have to be reported including retraceability to the standard unit metre, e.g. by measurement of calibrated reference artefacts. In non-industrial fields, e.g. cultural heritage or topographic surveying, the comparison of independent control points is a well-established method to derive accuracy figures. However, these points should not be included into orientation processes but should be measured individually in order to represent subsequent processes such as dense matching.

a) Surface sensor observed by external cameras (AICON).

b) Surface sensor with integrated camera (GOM).

Figure 3: Robot-guided surface measurement using fringe projection sensors.

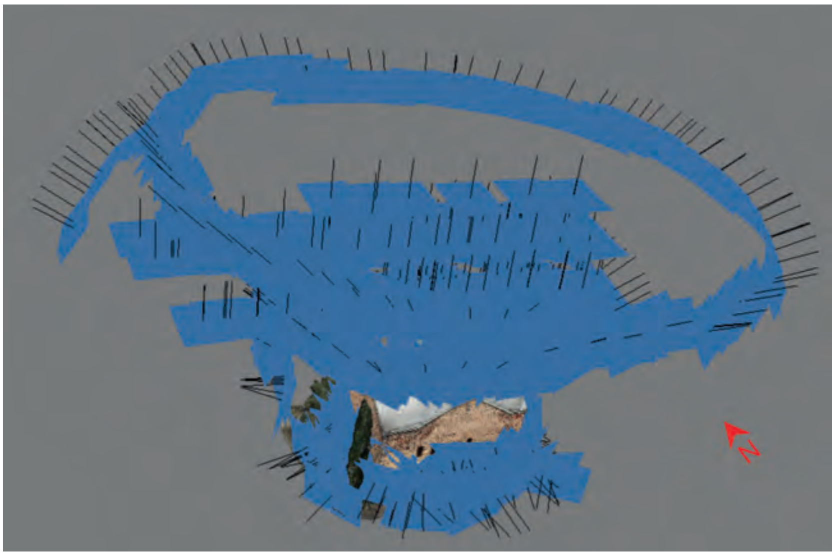
EXAMPLE: ROBOT-BASED INDUSTRIAL INSPECTION

Industry 4.0 is characterized by a number of significant changes in production, e.g. higher degree of individual products, shorter life cycles or more flexible manufacturing lines. For the past two decades photogrammetry has been successfully used in high-precision industrial metrology, e.g. in fields like inspection of tooling jigs by offline photogrammetry. Other examples include image-guided manual probing for measuring single 3D points with a touch probe, or fringe projection systems used as a standard tool for free-form surfaces.

A new direction of online systems uses robots to drive a surface sensor to specific areas of an object. Since the mechanical positioning accuracy of a robot is not high enough to provide the exterior orientation (pose) of the scanning device directly, a camera system observes the actual position of the sensor with respect to a pre-calibrated field of targets. This concept provides high flexibility to adapt for specific measurement conditions. Hence, it allows the integration of optical 3D measurement devices into flexible production lines.

Figure 3a shows a system in which a set of ceiling-mounted cameras measures the 6DOF pose of a fringe projection system.

Figure 3b illustrates a robot-based system in which a camera is attached to the surface sensor which permanently measures a set of reference targets.




▲ *Figure 4: Configuration of drone flights and resulting 3D model (IAPG).*

EXAMPLE: UAV PHOTOGRAMMETRY

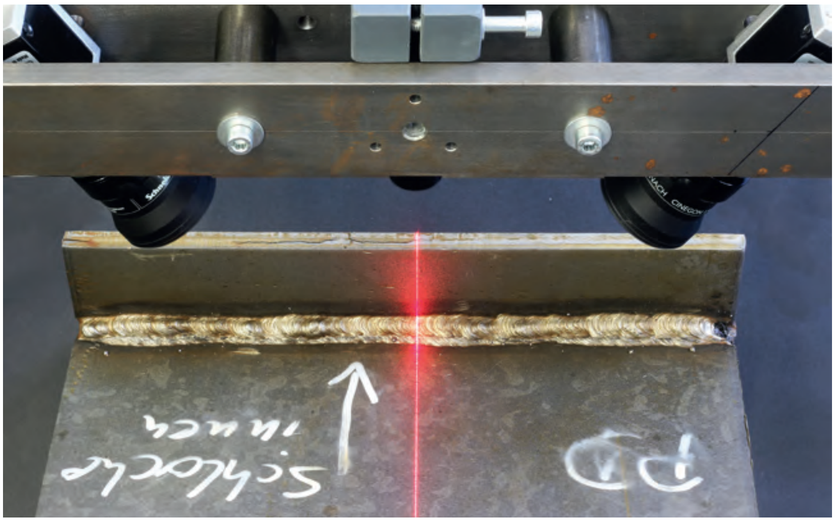
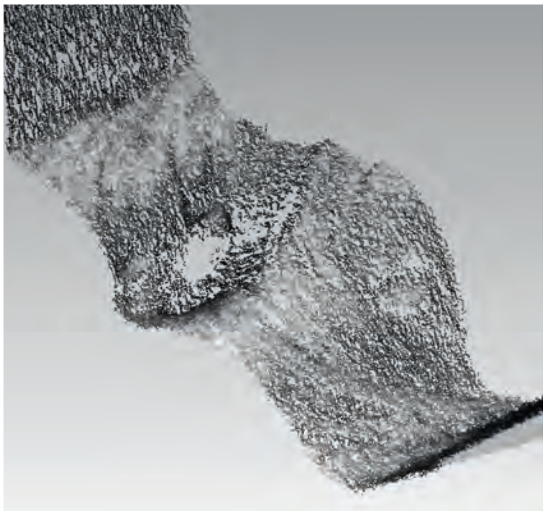
UAV-based photogrammetry has become a standard measuring technology now that remotely piloted drones with high capabilities for autonomous flying are available. With the relevant flight permissions, UAVs can be used as imaging platforms for a wide area of applications, e.g. road mapping, observation of construction sites, archaeological surveys, topographic mapping, environmental monitoring, etc. In most cases, recorded images are processed by SfM software that automatically generates point clouds or orthophotos.

Since many users have only limited photogrammetry skills, they do not always properly understand the impact of image configurations, distribution of control points or camera calibration issues. Consequently, the quality of results not only varies from project to project, but can also vary within a certain area of measurement within a project.

The professional use of UAV photogrammetry usually requires a high-quality camera/lens system, camera stabilization, dense image overlaps, sufficient intersection angles and a suitable distribution of control points, just as with aerial photogrammetry. Camera calibration can be particularly difficult when using non-professional cameras and/or weak flight configurations.

USERS OF UAVS DO NOT ALWAYS PROPERLY UNDERSTAND THE IMPACT OF IMAGE CONFIGURATIONS, DISTRIBUTION OF CONTROL POINTS OR CAMERA CALIBRATION ISSUES

Figure 4 shows an example of the use of an amateur drone (DJI Mavic Pro) for recording the roof areas of an ancient church. Although the drone was guided manually and the camera is not designed for measurements, configuring flights at different heights and the additional circular arrangement of images enabled the simultaneous calibration of the camera. Together with additional terrestrial images taken with a 24MP DSLR camera, a consistent and accurate 3D model with an average accuracy of 0.6 pixels (GSD between

▲ *Figure 5: Prototype sensor for weld measurement (IAPG).*

5-10mm) could be generated by an SfM approach (RealityCapture).

EXAMPLE: UNDERWATER WELD MEASUREMENT

In this example of measuring welding seams of underwater steel constructions, the objective is to measure the surface of welds with an accuracy and a resolution of about 30μm in a distance of about 50mm. Two variants of a prototype system have been developed. One solution consists of a laser line projector and two cameras that observe the projected laser line for stereo matching. The second version uses one or two cameras that are moved across a reference field with control points in order to derive the exterior orientations. The surface within overlapping areas is reconstructed by photogrammetric image matching.

CONCLUSION

Recent trends and developments from photogrammetry and computer vision indicate a continuous change of classical measurement technologies which could be classified as a paradigm shift. A wide area of new applications is now addressed, leading to new prospects and challenges. However, whilst new automated imaging technologies increasingly cover dynamic scene recordings, the proper use of these methods by users with limited skills may lead to unsafe or unforeseen results. Hence, appropriate teaching concepts for students as well as life-long learning offers for practitioners are urgently required. ◀

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Thomas Luhmann is a professor of photogrammetry and remote sensing at the Jade University of Applied Sciences in Oldenburg, Germany. His teaching subjects are photogrammetry, remote sensing and digital image processing, while his research areas include close-range photogrammetry, camera calibaration and panorama and dynamic photogrammetry. Since 2008, Luhmann has been acting as co-chairman of ISPRS Working Group V/1 'Vision Metrology'. In 2010, he was honoured with the Karl-Kraus-Medal of ISPRS.

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BUILDING THE CAPABILITY FOR HIGH-DENSITY 3D DATA

Technologies for the Future: **A Lidar Overview**

Point clouds can be captured by an ever-increasing number of means to understand the surrounding reality and detect critical developments. Diverse applications of 3D laser scanning or 'Lidar', which is a technology on a sky-rocketing path to be used for mapping and surveying, are changing the way we collect and refine topographic data. Which technologies and processes are building the capability for high-density 3D data? This article outlines the latest industry developments.

National topographic databases store data refined from field measurements, imagery and laser scanning data at certain specifications and purposes, but lack the ability to adapt to ever-changing needs and situational awareness. 'Data on demand' is a recognized megatrend in the geospatial industry.

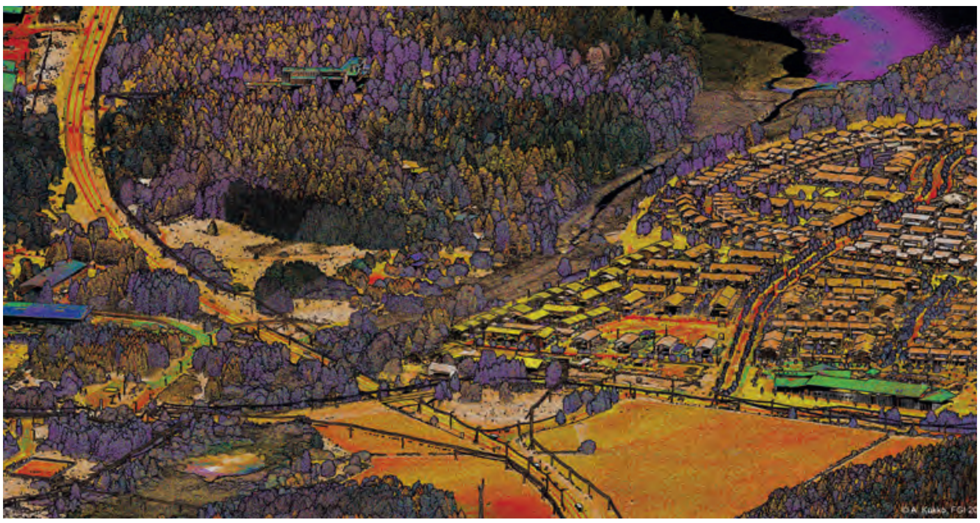
Point cloud data can be captured with an ever-increasing number of means – e.g. ground-based, airborne and spaceborne platforms – to understand the surrounding reality, from grain scale to global overview. Different scales and viewpoints can provide comprehensive multimodal data for environmental analysis, assessment of natural resources, development of urban infrastructure, and critical services. Semantic point clouds, temporal coverage, multimodal data sources, and automated processing form the framework for the future topographic data.

LIDAR TECHNOLOGIES

Laser scanning is based on the use of optically directed Lidar beams to collect object information in direct 3D measurements. This allows the system trajectory (i.e. position and attitude), to be produced robustly and accurately. Prior to the mid-1990s, GNSS-IMU technology was not affordable for commercial use. Since then, however, the market for devices has exploded, especially with the development of fibre-optic gyroscopes (FOG) and microelectromechanical systems (MEMS) technologies. Also, the buildup of nationwide GNSS base station networks has contributed to the success of Lidar in surveying and mapping in all its variety.

What makes Lidar so effective in topographic mapping is the capability to direct 3D measurements for the target and penetration of the beam through vegetation to collect information from objects and the ground beneath. The light wave front passing through the vegetation produces information on the vegetation as a side product. To yield such information, certain principles of laser ranging have to be deployed. The traditional way to gain long-range measurements is to shoot powerful laser pulses towards the target and collect the backscattering signal. The signal is then processed to detect objects at distinct ranges within the beam illumination area. These systems are the current mainstream and use a selection of spectral wavelengths to convey the data collection.

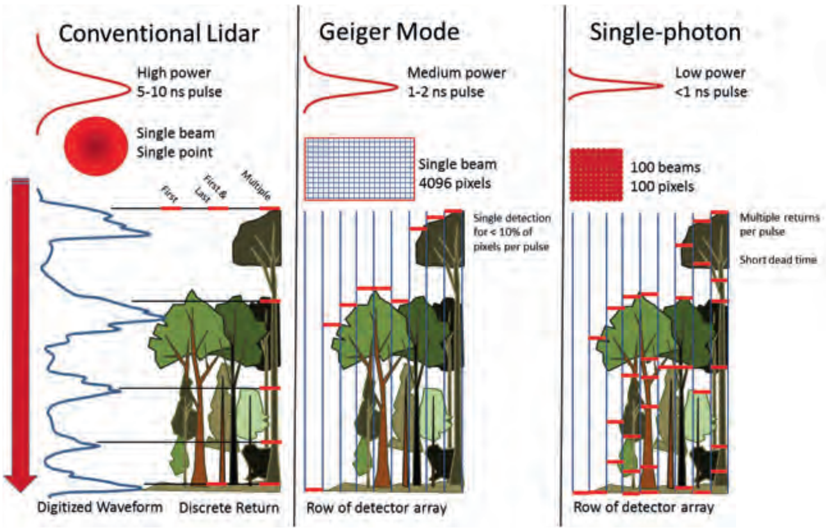
However, for spaceborne applications, this has proved problematic due to the excessive power needed to reach the Earth's surface from orbit, because of the havoc heat causes for the optical components. A novel emerging technology is to harvest the energies at the single-photon level, reducing stress on the optics. Some single-photon devices available



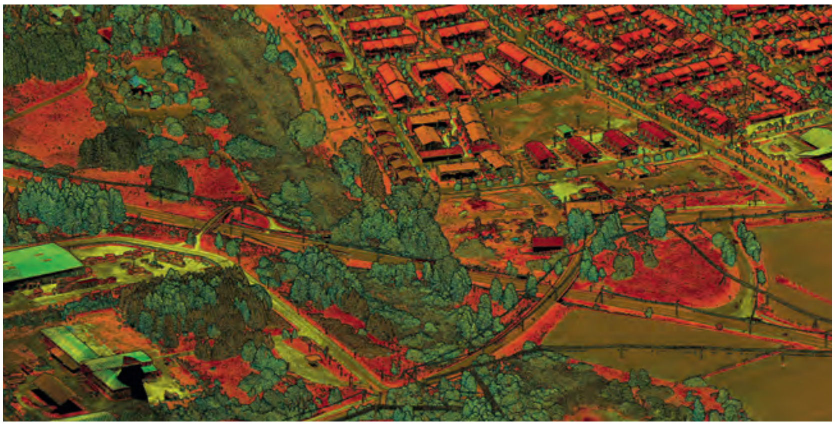
▲ *Figure 1: Dense and geometrically accurate point cloud offers photographic 3D capture of the reality for mapping, modelling and monitoring. Spectral information from Lidar will have significant implications on automated data interpretation.*

in the market promise high data-collection efficiency due to the high altitudes permitted by the sensitive detection. On the other hand, cloudiness sets limits for achieving the full potential in practice. The detector does not sample each returning photon but instead at detector-specific probability, and photons from other sources are detected in addition to those emitted by the Lidar source. This stochastic nature of detection forces adaptation of data processing methodology, because data characteristics and implications on data accuracy and processing are not yet fully commonly understood.

There are currently two techniques implemented for single-photon detection. In the Harris Geiger mode system, each detector pixel for a single pulse is occupied with the first photon received and no data beyond that is captured. Detection efficiency is less than 10%. Large-size detectors compensate these two characteristic features, and the data products typically give 8 or 32 points per square metre. However, penetration under vegetation remains somewhat uncertain. In the Leica SPL100 single-photon Lidar sensor, multiple targets are detected for each pulse per pixel after a short dead time of the detector when triggered by a photon. This gives penetration capability similarly to conventional Lidar. However, more analysis is needed to find out the pros and cons of these technologies unambiguously.



▲ *Figure 2: Principles of certain Lidar modes. The most complete signal is recorded with full-waveform Lidar. On-the-fly detection and single-photon techniques reproduce discrete sampling. Increasing the scan angle has an effect on the signal as per the changing light path through the canopy.*



▲ *Figure 3: In the future, increasingly detailed models and maps could be generated based on high-resolution airborne laser scanning (ALS) data. Multiple terrain and infrastructure features can be captured in a single flight to save cost. Complementary data can be collected with unmanned aerial vehicles (UAVs or 'drones') and ground-based mobile laser scanning (MLS).*

AIRBORNE LIDAR

Topographic surveys from the air form the firm basis of mapping. Information needs include ground elevation, building and network infrastructural assets and development. Airborne laser scanning is a two-decade old technology used to produce information for national mapping agencies, municipalities, and engineering companies, to fulfil the needs of communities, decision-makers and land-use planners.

Airborne Lidar data is collected for projects and data needs exhibiting various scales. For maximum detail, the data is collected from low-altitude flights (50-300m) at millimetre-level accuracy for utility mapping and civil engineering (e.g. RIEGL VUX-240, or Optech ORION C300-1). The data densities at this level are at tens or hundreds of points per square metre. For road and urban planning, mid-altitude (400-1,000m) scanning is often used and the data density is typically around a couple of dozen points per square metre.

Country-scale mapping flights are conducted using high altitudes (2,000m and up) for efficiency, and data densities are less than ten points per square metre, typically 1-2. The latest instruments for these applications on the market are the Leica Terrain Mapper, Optech ALTM Pegasus and RIEGL VQ-1560i.

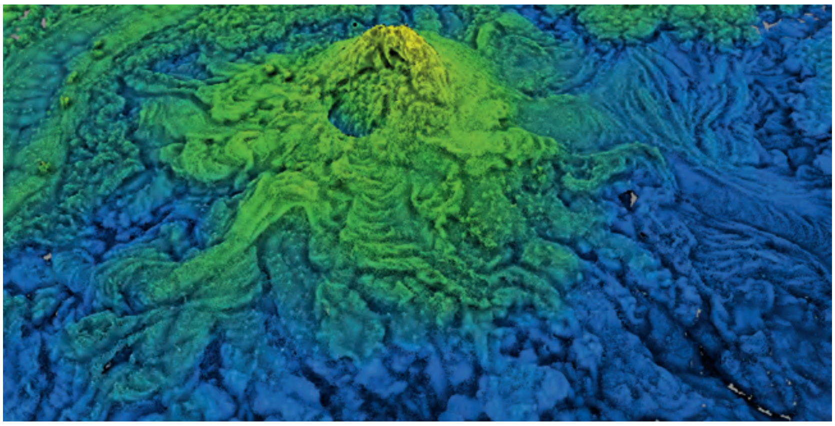
MULTI-PLATFORM MOBILE LASER SCANNING

Vehicle-mounted laser scanning systems have proven to be very efficient in measuring road and city environments. Multi-platform systems expand the use cases of MLS to natural environments, industrial installations and urban environments that cannot be easily accessed by a vehicle-mounted system. With the development of algorithms that allow simultaneous localization and mapping (SLAM), mobile laser scanning has also advanced to provide 3D data from global navigation satellite system (GNSS) denied environments, e.g. indoors and industrial sites.

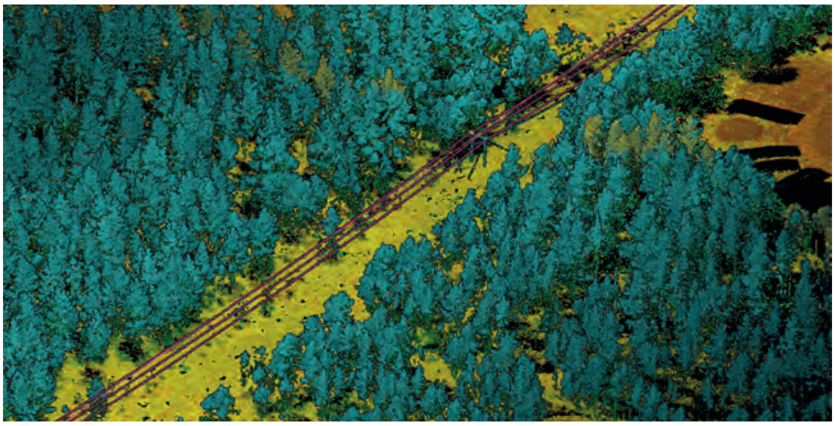
In this field, sensor technology is still experiencing a significant reduction in size and price. Simultaneously, the performance and accuracy has been improved to provide detailed 3D structural information on tunnels, roads, urban scenes and industrial sites. While a few years back certain industrial scanners were not able to be synchronized to an external positioning system, current sensors are usually pretty easy to integrate on multi-sensor platforms. Small sizes and easy integration allow systems to be adapted for diverse 3D measurement needs. We have seen MLS mounted on cars, trains, all-terrain vehicles (ATVs), boats and tractors in the past, and new applications using kinematic data collection will no doubt emerge in the future.

DRONES AND LIDAR

Unmanned aerial systems (UASs) constitute an increasingly important segment of engineering. Mapping and surveying drones provide an easy-to-deploy platform for aerial views of an area of interest. Currently there are some factors limiting the use of drones regarding operation time and development of regulation in many countries. At best, drones contribute to the production of valuable 3D and image data for needs in various engineering projects, urban planning and scientific tasks. Sensor pools are expanding rapidly, and small sensors are already available for UAS-Lidar applications, depending on the drone scale, such as the RIEGL MiniVUX-1UAV and Velodyne Buck LITE in the conventional category, and the Cepton SORA200 in solid-state implementation. Longer ranges and faster data rates are becoming available for this segment to enhance the data products and broaden the application envelope.



▲ *Figure 4: Backpack Lidar-mapped spatter cone and adjacent lava field. Such applications permit better understanding of natural processes and mitigation of hazards, but also bring possibilities in exploration and planetary research.*



▲ *Figure 5: Mapping and monitoring of power grid facilities and other structures critical to our everyday life and function is a prominent application of airborne and UAS-Lidar.*

▲ *Figure 6: GNSS-free SLAM and LOAM solutions could provide 3D data in almost real time, which is a desired feature for time-critical applications such as emergency response. Could Lidar systems help firefighters to navigate in smoke and detect victims in limited visibility in the future?*

The clear development trends are towards automated systems and real-time data processing. Also, longer operation times for UAVs are achieved with improved avionics, battery life and indigenous ideas, such as the Avartek Boxer Hybrid drone with 2-4 hours' flight time. Small but high-performance sensors and real-time data are the most relevant needs for drones, and typically limited project areas do not necessitate the presence of a GNSS-IMU; data is processed to a local coordinate system using techniques prevailing within the robotics community. However, ever-smaller and more capable GNSS-IMUs, like the NovAtel CPT7 or SBG Ellipse2-D are available, and with decreasing prices, direct georeferencing reduces the effort for ground control.

SLAM/LOAM LASER MAPPING

GNSS-free laser scanning is developing rapidly. Systems typically consist of low-cost laser scanners and inertial measurement units. Lidar data is used, and on some occasions augmented with visual odometry from cameras, to compensate for instantaneous movements of the sensor system, to calibrate low-performance IMU, and to keep track of the sensor and/or platform pose. These mapping solutions provide real-time or near-real-time 3D data for tasks with moderate accuracy needs. The development has been possible due to the miniaturization of sensors and SLAM, Lidar odometry and mapping (LOAM) and related algorithms. Multi-layer scanning in particular has proven to give sufficient information to estimate platform movements from single scans. Algorithms for scan matching with such data perform reasonably well and reliably to give good pose estimations, and are able to detect loop closures for global drift mitigation. A couple of examples are the Gexcel HERON, GeoSLAM Zeb Horizon and Kaarta Stencil systems, all based on Velodyne's Lidar Puck scanner. Notably, many companies are planning to bring similar sensor products on to the market, among them devices from RoboSense and Ouster.

In the area of terrestrial laser scanning, automated registration of scans has seen an interesting development implemented in the Leica RTC360. The scanner is implemented with image-augmented inertial measurements to compensate for movements between scan stations, thus speeding up the scanning work on site. Beyond that, use of Lidar for measuring submerged structures and objects is of increasing interest in the maritime industry, and kinematics-based localization systems using inertial and data-matching techniques are applied similarly to the counterparts on the ground.

MULTIMODAL MAPPING

Affordable but high-performance systems are already changing the ways of producing topographic data. Unmanned drones are an emerging technology that, coupled with advanced systems featuring laser scanning and imaging sensors, allows for rapid aerial data for various purposes. Combining UAV-based airborne sensors and mobile laser scanning with imagery brings together the flexibility of mobile systems and allows for short response times and low mobilization costs. Use of these systems provides data with minimal occlusions enabled by easily accessed viewpoints. This data typically represents the objects of interest at a very high level of detail (LOD) down to a scale of a single railing, cable or sign.

Vehicle-mounted kinematic mapping systems are useful for road and street data capture for mapping and maintenance purposes. Such data provides high-density base map data for autonomous driving – an example of a new kind of mapping for the future. Backpack scanning is a suitable method of collecting 3D data from cultural heritage sites, buildings, streets and terrain.

GNSS-IMU and SLAM-based laser scanning systems can be mounted on virtually any kind of platform to carry out tasks in variable environments, and for variable data requirements and scales.

AUTONOMOUS VEHICLES AND CROWDSOURCED MAPPING

Autonomous vehicles have attracted considerable industrial interest in recent years. Following the DARPA Grand Challenge

competition for self-driving cars, several major manufacturers have announced their future goals of providing autonomous vehicles. This requires fitting the vehicles with highly capable 3D mapping systems, much like those encountered in contemporary MLS. For the geospatial information community, these future autonomous vehicles are a potential source of highly detailed and frequently updated 3D mapping data.

In addition to vehicles, 3D mapping capabilities are increasingly carried by consumers in their smart devices – simply put, smartphone camera images and positioning information may contribute to mapping. More capabilities are offered by other sensors such as depth cameras and 3D image interpretation. These technological developments hold the potential to replace the prevailing centralized mapping conventions with decentralized, distributed and frequent crowdsourced mapping.

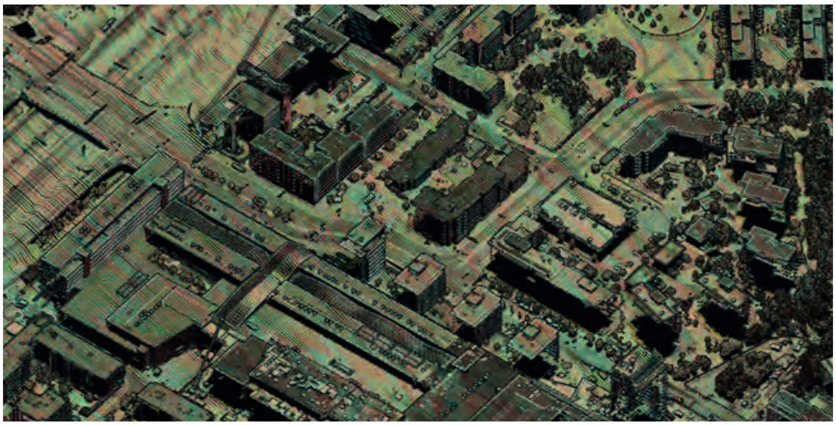
▲ *Figure 7: High-density mobile laser scanning data permits cadastre, and urban planning and management. Reflectance data can be used in object interpretation.*

MULTISPECTRAL SENSORS – COLOUR VISION WITH LASERS

Multispectral laser scanning technology is currently in its technological adaptation phase in ALS, promising an increase of active spectral information for mapping and detection. The first example of this was the recording of laser backscatter intensity and the use of the intensity values in the visualization of point clouds and in certain classification tasks. The emerging multispectral laser scanning (e.g. Optech Titan for ALS) increases the amount and quality of spectral information obtainable. However, the current implementation is not optimal for acquiring spectral information due to distinct scan angles and patterns for each channel, and data needs to be interpolated for analysis. Alternatively, the RIEGL 1560i-DW provides a two-wavelength instrument.

Actively sensed radiometric properties of target objects do not suffer from illumination variations and anomalies caused by solar illumination present in passive imaging products. The autonomous driving industry is predicted to explore this opportunity in the future, as well as forecasting the availability of small form-factor sensors.

Classification results with the data from the first multispectral ALS systems have been promising. For example, a very high overall accuracy (96%) of land cover classification results has been achieved in some studies, with six classification categories (building, tree, asphalt, gravel, rocky, low vegetation).



▲ *Figure 8: Multispectral Lidar point cloud from Optech TITAN representing the urban environment. Combined data at different wavelength regions helps greatly in classification and object recognition. Differing scan patterns for each channel become visible in the raw point cloud data.*

SINGLE-PHOTON SYSTEMS

Single-photon technology is an emerging technological breakthrough for airborne laser scanning. Single-photon systems require only one detected photon compared to hundreds or even thousands of photons needed in conventional Lidar. As a result, pulse densities of ten to a hundred times higher can be attained compared with conventional sensors. In addition, the sensitivity of the detector to energies in the single photon range allows the systems to attain higher maximum ranges and remain eye-safe. This has also contributed to the recent launch of ATLAS, a spaceborne Lidar-based sensor for global monitoring aboard ICESat-2. Similarly, the single-photon technology will be used in autonomous driving and drone sensors before long.

Single-photon data are available currently from two sensors: Leica SPL100 and Harris Geiger-mode Lidar. The operational differences, albeit generally similar, can be deciphered in Figure 2 and compared to the conventional one. Both single-photon systems available are implemented to use green light (532nm) that makes them suitable for use in bathymetric mapping as well. There are also single-photon detectors available, both on the market and in research labs, allowing miniaturized systems for UAV scale in the near future. Sensitive detection is expected to improve the depth data, although it will ▶

still take some time to perfect the processing methodologies and harness the full potential.

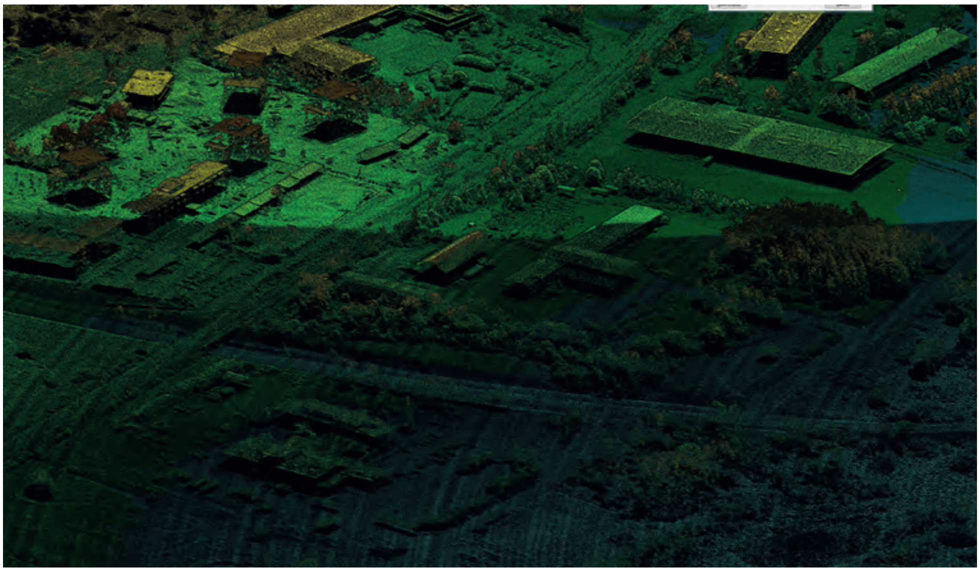
IMPLICATIONS OF HIGH-RESOLUTION LIDAR

The developments in acquiring point cloud and spectral data significantly increase the data volumes produced. Automation is needed in order to transform the increased measuring frequency and point cloud density into efficiency and a high level of detail in mapping. The emergence of national laser scanning campaigns, such as those in the Netherlands, Sweden and Finland, highlights the need for automated processing methods.

On a more limited scale, multi-temporal point clouds have been applied to change detection both in the urban and natural areas, for management of resources and coping with hazards, effectively showing the potential of multi-temporal 3D data. Combining these methods with automation and periodically repeated country-wide scanning campaigns would allow spectral and geometrical change detection in unseen detail for improved understanding of natural resources and the biosphere.

In addition to change detection, automation is required for various modelling tasks. In urban environments, automated generation of simple building models has become the default approach for 3D city modelling. Several algorithms for detailed building modelling have been introduced, potentially raising the level of detail in automated modelling. In a similar fashion, algorithms have been introduced for modelling road environment objects from dense mobile laser scanning point clouds. In natural environments and forestry, point cloud datasets have been applied both for producing parameter information over larger areas (e.g. for hydraulic modelling and flooding analysis or permafrost processes), and detailed modelling of individual trees for forest resource and biomass assessments.

Ideally, the change detection, mapping and modelling should be combined with periodical 3D data acquisition at intervals of just a few years. Based on multi-temporal data, possible changes can be detected, identified or classified based on spectral and geometric features, and modelling, maintenance or any similar action or effort can be focused based on data-derived signals or early warnings to save costs or avoid indirect damage.



▲ *Figure 9: Leica SPL-100 single-photon elevation point cloud data (coloured). In the foreground, only data points from the forward part of the scanning cone are shown, revealing the scan pattern on the ground.*

SUMMARY

Current topographic databases are commonly based on aerial images and maintained by national mapping agencies with a significant amount of manual work. Developments in laser scanning and point cloud processing could provide significant cost savings via automation of mapping processed with improved output and quality of data.

Multimodal Lidar data will increasingly be used in the future thanks to the development and availability of capable sensor technologies. Ever-smaller systems with similar or improved performance will provide applications using virtually any platform to operate Lidar for mapping and surveying. Aircraft, drones, vehicles, backpacks and handheld mapping systems all serve as means to gather complementary data for virtually any task imaginable.

Emerging single-photon technology has the most potential as a sensor solution for providing dense point clouds with low unit costs for country-level data acquisition. Multimodal laser scanning from airborne and terrestrial perspectives can be utilized for obtaining more detailed data from selected areas.

Dense point clouds with multispectral information provide a common starting point for automated modelling workflows and direct visualization applications, forming the future topographic core data. They represent a significant asset for business in improved forestry and infrastructure management, and provide a platform for developing several future applications. ◀

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The **Relevance of Aerial Mapping** in 2019 and Beyond

Reality 3D models, Lidar points clouds, superhigh-resolution aerial imagery and artificial intelligence from aerial imagery… these are just a few of the products derived from aerial mapping that the GIS sector takes for granted in 2019. Despite the plethora of high-resolution Earth observation satellites and the exponentially increasing impact of drones on the aerial mapping sector, most large and medium-scale 'topographic' or GIS map data is still derived from manned aircraft, whether fixed-wing or rotary. But the multitude of systems and processes can make selecting the correct aerial mapping technology a complicated and confusing process. This article takes a brief look at the latest aerial mapping systems and processes, along with the ever-expanding range of products and services derived from such systems.

The development of aerial mapping from manned aircraft can be largely traced back to military applications developed between the First and Second World Wars. From the 1950s onwards, photogrammetric mapping from large-format aerial film cameras became commonplace in civilian life, as governments and (to a lesser extent) the private sector adopted photogrammetry for small and medium-scale topographic mapping.
Entire continents were mapping using the specialized film cameras and optomechanical 'stereo plotting' machines developed by companies including Wild (Leica), Zeiss and Kern.
The beginning of the 'digital era' around the turn of the 21st century saw the commercial introduction of airborne Lidar systems that directly measured thousands of ground points per second, along with the move to fully digital cameras and high-powered computers for data processing. New digital workflows saw the previously under-utilized ortho-rectified photo map (orthophoto) rapidly evolve to become a 'de facto' base map, especially for large-scale GIS and mapping applications. The last decade years has seen the development of more and varied airborne sensors and downstream digital production. Data capture and production is faster and more cost-effective than ever. Aerial mapping and the multitude of derived products mean that users have more options to map, measure, visualize and interpret the natural and built environment than ever before.


Government of India
Ministry of Science & Technology
Survey of India
LOAN no: 8725-IN
INTERNATIONAL COMPETITIVE BIDDING

PROCUREMENT OF NON-CONSULTANCY SERVICES UNDER ICB

for
Provision of services for Acquisition, Processing and Delivery of DEM and Digital Ortho-Image

ICB #: IN-SOI-51103-NC-RFB Dated 08-August-2018
Project: NATIONAL HYDROLOGY PROJECT

Employer: Surveyor General of India, Survey of India, Dehra Dun

Country: India

Issued on: 08-August-2018

Figure 1: Survey of India procurement request for aerial mapping services.

IMAGING SENSORS

Today's aerial cameras can capture hundreds of megabits of data per second, with resolutions ranging from 70cm to 1-2cm and coverages of up to 1,000km per hour. Aerial cameras come in a range of configurations, from conventional vertical-looking cameras to sweeping and push-broom sensors (similar to satellite imaging sensors), vertical and oblique configurations and focal lenses supporting high and low-level aerial mapping applications. Most modern aerial camera sensors incorporate an integrated positioning system that provides extremely precise absolute camera position (X,Y,Z) and camera orientation (pitch, roll and drift angle) information for each camera exposure (image). The integration of high-quality positioning systems from companies such as Applanix with its POS AV range provides a direct georeferencing ability that dramatically reduces the need for ground control and test points to accurately 'position' the aerial survey. Many aerial cameras also incorporate a gyro-stabilized mounting system that enables the aerial camera system to maintain a consistent (almost perfectly stable) orientation, irrespective of the angle of the aircraft. Such systems help to improve the quality of aerial imagery as well as the downstream data processing.
The majority of modern aerial camera systems are still mounted in either single or twin-engine, manned, fixed-wing aircraft. In most cases, specifically modified aircraft are required (i.e. the aircraft has a camera 'hatch' cut into its base where the aerial

camera system is mounted), although some newer aerial camera systems – such as the Simplex aerial camera – can be externally mounted. Smaller systems such as PhaseOne and MIDAS aerial camera systems can also be mounted in helicopters. Whilst copters are generally more expensive to operate than fixed-wing aircraft and generally do not have the same flying speed (and hence capture speed), they are suitable for small-area projects or linear aerial mapping projects such as power lines or road and railway line surveys.

Most commercial aerial camera systems incorporate proprietary software (and sometimes firmware) for pre-processing and initial georeferencing of the captured imagery, e.g. Leica HxMap, VisionMap LightSpeed and Vexcel UltraMap. Once pre-processing of the imagery is complete, there are numerous software packages and Software as a Service (SaaS) solutions that further process the aerial imagery into derived products, e.g. BAE Systems Socet Set, Trimble Inpho and Simactive's Correlator 3D.

VERTICAL IMAGE SENSORS (AERIAL CAMERAS)

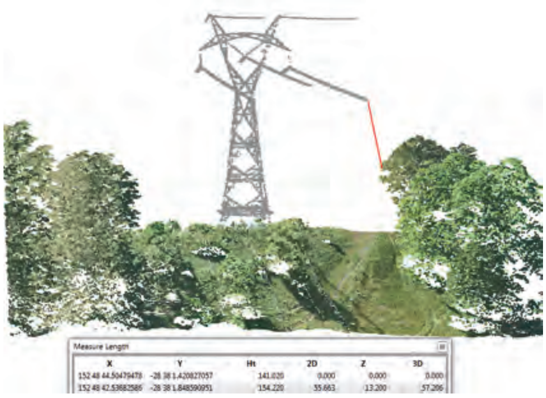
Despite the large variety of aerial sensors now available, the vertical aerial camera capturing overlapping (stereoscopic) imagery remains the most common aerial imaging system in use. The general applications range from wide-area imaging and mapping, right down to very-high-resolution, small-area and linear (corridor) mapping.

WIDE-AREA IMAGING SENSORS

Large-area, medium to high-resolution aerial photography continues to be a large part of the aerial imaging market. Much of this wide-area image capture supports national or regional government mapping programmes, although in most countries the aerial capture work is largely undertaken by the private sector. Applications for wide-area mapping include traditional topographic mapping, border protection and homeland security, agriculture and forestry monitoring, generation of digital elevation models (DEMs) for flood plain and water catchment management, for instance, as well as land tenure and land use mapping. In developing countries, wide-area mapping projects are often funded by donor agencies such as The World Bank or regional development banks. Examples of wide-area aerial mapping projects include the mapping component of the Indian National Hydrology project managed by the Survey of India (see Figure 1) and the US government's National Agriculture Imagery Program (NAIP).

Modern wide-area sensors collect at higher resolutions than satellite imagery (anywhere from 5cm to 70cm) and are capable of covering thousands of kilometres per hour. Wide-area vertical sensors typically acquire imagery across the three visual spectral bands (RGB) as well as the near-infrared spectral band. These aerial sensors typically incorporate lenses with a relatively short

▲ *Figure 3: Singapore's Virtual Singapore project is based on the framework of highly accurate 3D city models built from aerial mapping.*



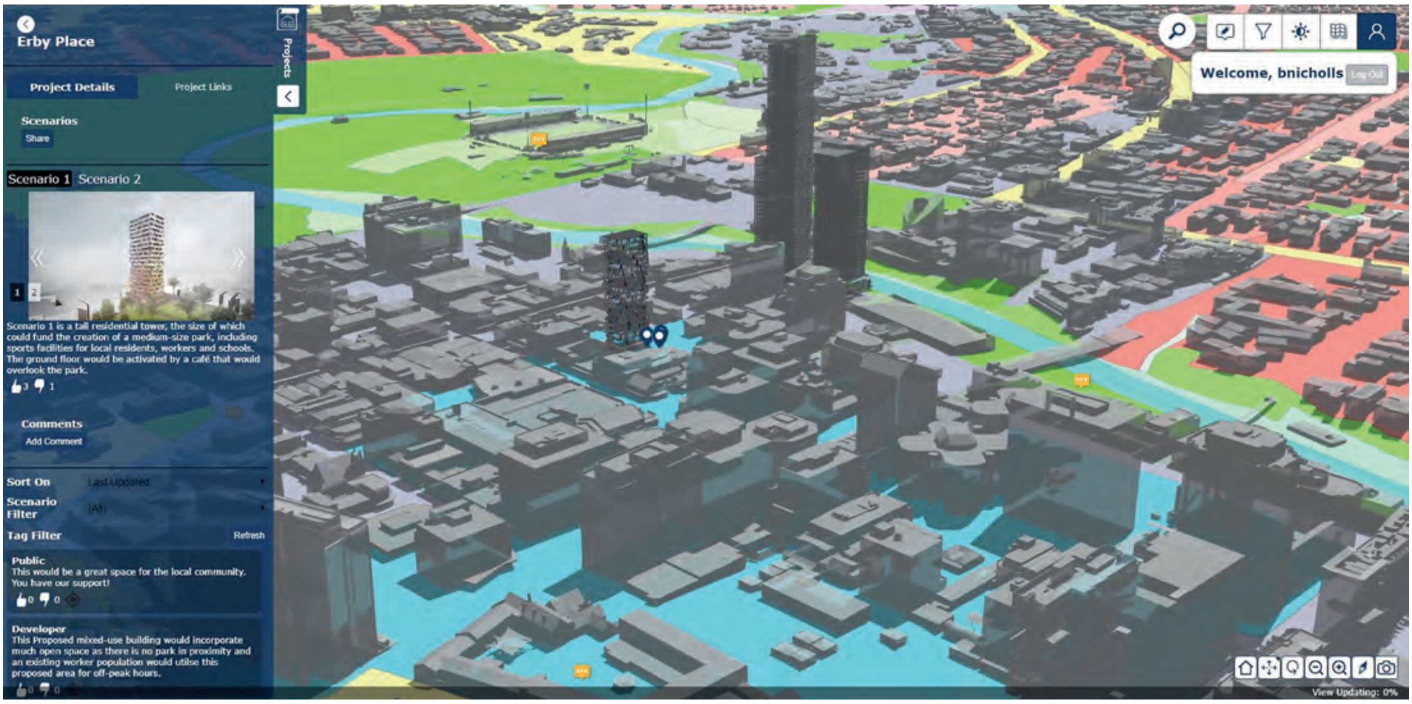
▲ *Figure 2: Airborne Lidar data for powerline mapping and monitoring.*

focal length, allowing for flying heights of up to 3,000 to 4,000m above ground level. The relatively short focal length provides a wide field of view which – coupled with very large image sensor arrays – facilitates very rapid, large-area collection. For example, the UltraCam Condor captures a 9km swath width at 25cm image resolution which equates to roughly 800km^2 of coverage per hour. Sensors in this category are typically supplied by the traditional aerial camera vendors and include the Leica ADS100 and DMC III and the Vexcel UltraCam Condor.

HIGH-RESOLUTION IMAGING SENSORS

Small-area, high-resolution (7.5cm to 20cm) and very-high-resolution (< 7.5cm) aerial imaging has exploded in popularity over the past ten years. Ever-higher-resolution digital sensor arrays, digital motion compensation, decreasing sensor size, weight and cost, and ongoing exponential increases in computer processing and storage mean that the capture and processing of high-resolution aerial imaging has never been easier or more affordable – not to mention the impact of drones on this market segment.

Applications for high-resolution aerial mapping include both area-based (e.g. city-wide mapping or full-site mining survey) projects and linear-based ones (e.g. existing roads, railways or power lines or planned linear infrastructure). As per wide-area aerial imaging, the (very) high-resolution digital orthophoto or orthomosaic has become the de facto base map or product for high-resolution aerial imaging. Applications for this sector include municipal mapping for engineering, town planning and asset management, maintenance of existing infrastructure and planning for new infrastructure (e.g. roads, rail, pipelines,



▲ *Figure 4: The Urban Pinboard application is based on highly detailed 3D models built from aerial mapping (www.urbanpinboard.com).*

renewable energy projects), mining, quarry and stockpile mapping, forestry and agriculture, etc.

The aerial sensors available include the traditional aerial mapping vendors (e.g. Leica and Vexcel) along with many other players including VisionMap with the A3 Edge sensor that combines very high resolution with extremely rapid data capture rates. In the past few years, we have seen the emergence of companies such as PhaseOne, whose very-high-resolution cameras can be used as standalone camera systems or can be used by other system integrators to configure custom camera systems such as the MIDAS oblique camera system.

OBLIQUE IMAGE SENSORS (AERIAL CAMERAS)

An increasing number of 'oblique' aerial camera systems have been introduced over the past decade. Traditional oblique camera systems involve mounting a number of different lenses on a single camera mount, with each camera typically mounted at an approximate 45-degree angle to the horizon along with one conventional, vertically mounted lens. The additional oblique images are useful for projects such as urban asset mapping and construction of 3D city models. Over the past three years, the rapid emergence of 3D mesh modelling software and systems has produced an increased demand for oblique camera systems, since traditional vertical camera systems do not provide the 'look angles' or multiple views of the same point on the terrain surface required for successful 3D mesh modelling. Current systems include conventional oblique cameras by Vexcel and MiDAS as well as 'swinging' oblique systems such as the Simplex system.

LIDAR SENSORS

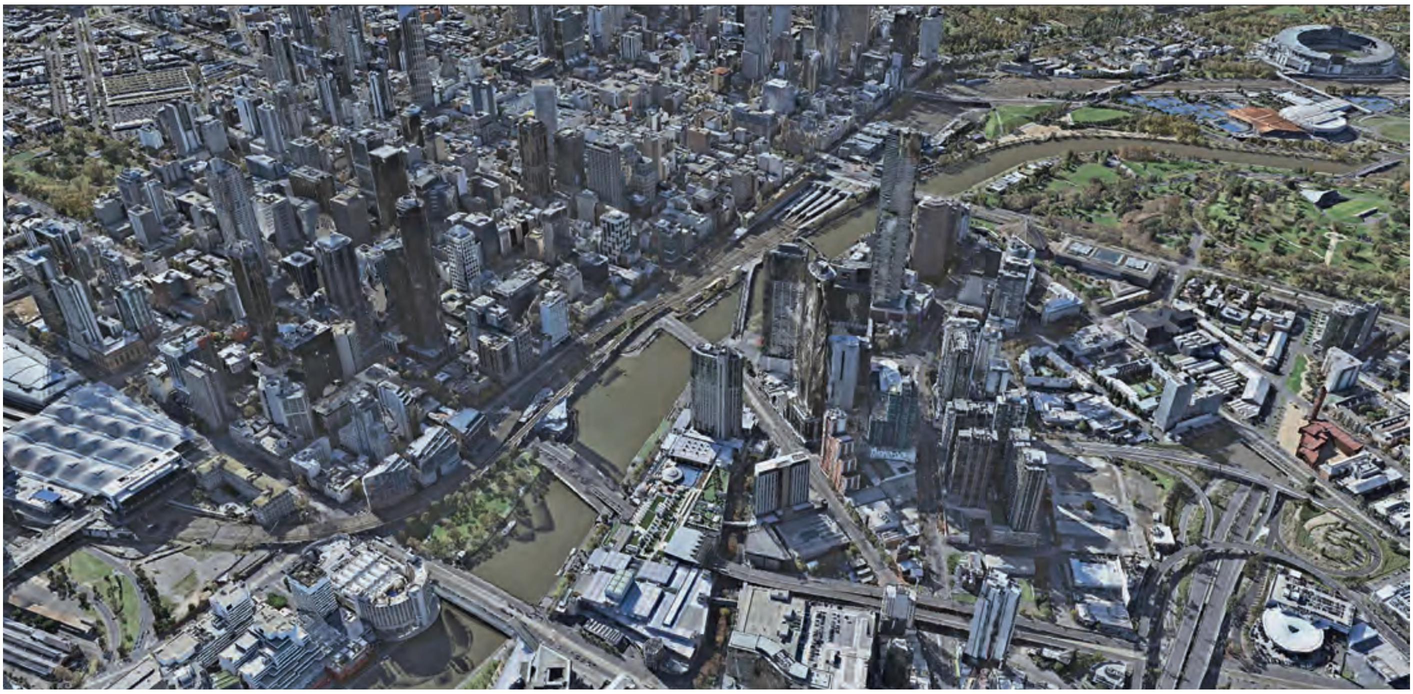
The emergence of airborne Lidar sensors in the early 2000s has revolutionized aerial mapping. Lidar sensors 'shoot' hundreds of thousands of laser pulses per second to the ground, effectively providing hundreds of thousands of direct distance measurements per second. When combined with a direct georeferencing system, these direct distance measurements allow the very rapid creation of digital terrain models (DTMs) and digital surface models (DSMs). The ability of the Lidar system to measure multiple laser returns means that airborne Lidar can even produce terrain models in thick vegetation, as some laser points inevitably reach the ground. The multiple return effect also provides the ability to measure multiple surfaces simultaneously, such as forest canopy or powerlines along with the ground surface. Most Lidar systems also provide an intensity value for each laser point, which can help to interpret from which type of surface or vegetation the laser beam is reflected.

Like aerial imaging sensors, most airborne Lidar sensors are now optimized for either wide-area coverage or small-area or corridor mapping coverage. Although more and more suppliers are emerging, the major suppliers of airborne Lidar systems remain Leica, RIEGL and Optech. Each supplier provides a range of instruments, varying in power, Lidar pulse rate, scan angle and scan rate, flying heights and weight/size, to suit a variety of applications and platforms. Airborne Lidar sensors can be mounted in fixed-wing and rotary platforms, with rotary platforms being more widely used than fixed-wing ones in aerial imaging applications, particularly in small-area and corridor applications.

Most modern airborne Lidar sensors are integrated with a vertical aerial camera system, such as by PhaseOne. This allows for the simultaneous capture of both Lidar and imaging where appropriate.

Modern Lidar systems have significantly evolved over the past few years. This results in greater point densities (4 to 10 points per square metre is now common) and faster capture rates. Point densities of 20 to 50 points per square metre are now routinely achievable, although there is a notable tradeoff between point density and capture time/cost.

Whilst modern digital aerial cameras and photogrammetric software can now generate very high-accuracy and high-resolution DSMs, Lidar remains the most appropriate tool for mapping terrain in areas covered by vegetation such as scrub or forests, or where



▲ *Figure 5: 3D reality mesh model of Melbourne, Australia, built from VisionMap A3 imagery and Bentley's Context Capture software.*

multiple 'surface returns' are required such as in powerline (Figure 2) or forestry mapping applications. Lidar sensors also typically measure the 'intensity' of the returned laser pulses, which assists in determining the type of surface from which the laser beam is reflected (e.g. roads vs footpaths vs trees, etc.)

SINGLE-PHOTON AND GEIGER-MODE AIRBORNE LIDAR

Over the past few years, some new sensors have begun to emerge that utilize a different laser-based measurement approach. These sensors can capture data at significantly greater flying heights and hence higher coverage rates than conventional airborne Lidar systems. However, accuracy and attribution may be affected, as the technology is commercially relatively new.

HYBRID SENSORS

As the range of imaging sensors and processing technology increases, so too does the number and type of sensors. It is now common to find commercial airborne mapping sensors that combine both high-quality aerial camera systems with airborne Lidar systems. These systems can be used in many areas; however, they appear to be especially well suited to the burgeoning field of high-resolution 3D city mapping (e.g. the Leica CityMapper airborne hybrid sensor).

DRONE MAPPING

There is absolutely no doubt that unmanned aerial vehicles or 'drones' are set to revolutionize the aerial mapping industry. There are literally hundreds of affordable commercial drones available. Coupled with a small vertical-looking camera or oblique camera systems and modern photogrammetric software, drones can create highly detailed maps, often at significantly lower cost than conventional mapping. Drones fitted with Lidar systems are now also becoming commonplace. However, drones are restricted in their use and application by multiple factors, including:

- Where they may fly (generally not in highly urbanized areas or within Civil Aviation-controlled zones and generally not beyond visual line of sight)
- The size and weight of the sensor they can carry
- The flying time for each flight
- The flying altitude and hence coverage area for mapping.

For small-area surveys, repeat-area surveys such as mine or quarry sites or for certain corridor mapping projects, drone mapping now presents a viable alternative to conventional mapping. However, users should be careful not to expect that a drone weighing 5kg, for instance, can achieve the same mapping accuracy and coverage as can be achieved with a manned aircraft fitted with a high-end aerial mapping system. As the Civil ▶

▲ *Figure 6: 3D reality mesh model of Copenhagen, Denmark, built using high-resolution oblique aerial imagery and Bentley's Context Capture software.*

▲ *Figure 7: 3D reality mesh model of a building in Brisbane, Australia, created using very-high-resolution drone-based imagery and Bentley's Context Capture software.*

FURTHER READING

www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/
www.youtube.com/watch?v=GbJ9xPf0gwg (for an overview of airborne Lidar systems)
www.faa.gov/news/fact_sheets/news_story.cfm?newsId=20516 (USA Federal Aviation (Part 107) Regulations)
www.opengeospatial.org/standards/citygml
www.youtube.com/watch?v=3HNjU5pT5Ck

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Aviation regulations regarding drone usage develop in parallel with drone technology, over the next few years drone-based mapping will increasingly open up new mapping applications and, to some extent, eat into the manned aerial mapping market.

PRODUCTS AND APPLICATIONS

As has been discussed above, the range of products and applications that can be derived from aerial mapping is constantly expanding. Image and point data resolutions continue to increase, orthophoto mosaics are a standard product, discrete 3D city models such as those specified by the Open GIS Consortium (OGC) CityGML standard have become increasingly common. Cities such as Singapore have based their entire 'smart city' framework on a very-high-resolution 3D city model built from aerial mapping techniques (Figure 3).

The relatively new 3D reality mesh models have created a quite an impact over the past few years and will continue to develop rapidly. Reality models can be generated rapidly and have found significant use in areas including infrastructure and construction as well as 3D city mapping.

BIG DATA, MACHINE LEARNING AND ARTIFICIAL INTELLIGENCE

The data captured from aerial mapping is, by its very nature, 'big data'. The rapidly developing fields of machine learning and artificial intelligence will make increasing use of the data products from aerial mapping. Applications range from automated building and feature extraction, e.g. for 3D smart city applications and autonomous vehicle maps, to automated detection of faults and vegetation encroaching on powerlines, to monitoring of forest and crop health. This trend is not yet fully developed, but it is certain that the amazingly detailed and accurate data available from aerial mapping will been utilized in ever-more automated ways in the next few years.

CONCLUSION

Aerial mapping continues to be a highly relevant, efficient and effective means to capture high-quality, highly accurate data for GIS and mapping applications. The range of sensors and derived products continues to expand, whilst the range of applications appears almost limitless. When considering aerial mapping as a method for capturing geospatial data, the user should keep in mind the primary purpose for the data capture exercise. Ideally, resist specifying the type of aircraft or aerial sensor and consult with specialist aerial mapping companies instead. These experts will be able to advise on the best approaches and options available to achieve the project outcomes required, whilst balancing operational logistics such as air traffic control, accuracy, quality, timeliness and cost of the survey. ◂

▲ *Figure 8: 3D reality mesh model of a building in Kuala Lumpur, Malaysia, created using very-high-resolution drone-based imagery and Bentley's Context Capture software. The right-hand side of the image illustrates the 'mesh' that provides the model framework.*

HOW THE BOOMING CONSTRUCTION BUSINESS BOOSTS THE GEOSPATIAL INDUSTRY

The Rising Demand for Total Stations and Terrestrial Laser Scanners

Increasing investments in large infrastructure and construction projects, and the rising role of building information modelling (BIM), are expected to drive the market for geospatial equipment. BIM's close connection with spatial information makes it a familiar landscape and offers rich possibilities for surveyors and other geospatial professionals. Geomares – publisher of *GIM International* and *Geo-matching* – has analysed the user data and behaviour of thousands of members of the global geospatial community. It is interesting to see how the market of 'traditional survey equipment' such as total stations and terrestrial laser scanners will respond to the growing construction market and the digitalization of this area.

Total stations and terrestrial laser scanners have a wide variety of capabilities and are extensively exploited in cadastral surveying, civil engineering and on construction sites. Surveying professionals use a mix of advanced technologies such as aerial and terrestrial photogrammetry and Lidar, but traditional ground surveys remain vital components of any building project. Data from global navigation satellite systems (GNSS) and total stations can be integrated with Lidar and photos to provide georeferencing and increased detail and precision. Despite the increased role of advanced technologies entering the geospatial world, market research states that the market outlook for total stations and terrestrial laser scanners is still very good. Two important reasons why these markets will keep growing over the coming years are the increasing investments in the construction market and the rising role of BIM – after all, the construction industry is undergoing a major transition towards digitalization.

RISING ROLE OF BIM IN THE CONSTRUCTION SECTOR

BIM is one of the most intriguing opportunities for surveyors to come along in years. BIM combines technologies and processes to support efficient creation and use of information for construction projects. Because of their expertise with spatial information, surveyors and other geospatial professionals are well positioned to become trusted participants in BIM-based construction projects. They can leverage their skills in 3D data management, modelling and visualization to support the 'design, build and operate' processes that lie at the core of BIM. Surveyors and other geospatial professionals would benefit from becoming highly skilled in BIM concepts and technologies that rely on spatial information so they can provide valuable services throughout a project's development, construction and operation stages.

Laser scanning is the connecting point between geomatics and BIM because point clouds are very important for creating building information models. From a spatial data perspective, one of the critical values of BIM is its capability to represent buildings at a finer level of detail, making it especially helpful in representing building interiors. It is clear that the growing role of BIM in the construction sector will have a strong impact on the geospatial market and that geospatial equipment has a vital role in the building information modelling process.

▲ *Figure 1:* Geo-matching *page views for total stations and terrestrial laser scanners.*

MARKET DATA ANALYSIS

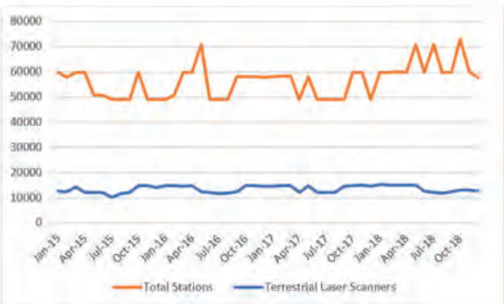
Of the 500,000 professionals that visited the *GIM International* and *Geo-matching* websites in 2018, a large percentage of them were interested in total stations and terrestrial laser scanners. This puts Geomares in a unique position to analyse website behaviour to discover trends and insights related to such products. The following overview is based on a combination of *Geo-matching* website data, Google search statistics and market research.

BEHAVIOUR OF GEO-MATCHING USERS

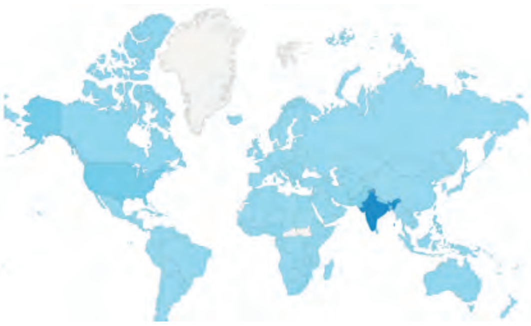
Total stations and terrestrial laser scanners are very important product categories of the *Geo-matching* website, with 120 products listed from 32 manufacturers. In 2018 there was strong growth in the number of page views for total stations with an 87% increase compared to 2017. Meanwhile, the number of page views for terrestrial laser scanners increased by 60% (see Figure 1). This indicates a rising demand for both geospatial data acquisition methods.

MARKET FORECASTS FOR TOTAL STATIONS AND TERRESTRIAL LASER SCANNERS

Surveying technologies, such as total stations and terrestrial laser scanners, are being adopted in a wide variety of application areas. Total stations are used for surveying, construction and engineering but also for transportation planning, forestry and land management, and for precision agriculture. For agricultural tasks related to precision farming, accurate in-field positioning is a necessity. Robotic total stations are gaining a lot of attention in the agricultural sector due to their increased accuracy. These new applications are expected to further drive the market for total stations and terrestrial laser scanners, especially in the Asia-Pacific region. Other growth factors include increased investments in the construction and infrastructure sector, and the rising role of BIM, especially in India, China and other countries in southern Asia. Initiatives for developing smart cities, and the corresponding need for BIM and geospatial technology, will further boost the market for total stations and terrestrial laser scanners. However, there are differences between both markets as explained below.



▲ *Figure 2: Google search terms for total stations and terrestrial laser scanners and related terms from 2015-2018.*



▲ *Figure 3: Regional distribution of* Geo-matching *users looking for total stations in 2018.*

THE TOTAL STATION MARKET FORECAST

Market research states that the Asia-Pacific region holds the biggest market share for total stations globally. North America also holds a significant market share and the growth in the transportation and construction sectors in countries like the USA, Canada, and Mexico is expected to further expand the market.

THE TERRESTRIAL LASER SCANNER MARKET FORECAST

The global market for terrestrial laser scanners is expected to grow over the coming years with Asia-Pacific anticipated to be the fastest growing region. The Asia-Pacific market is already the largest market, followed by North America and Europe. The Google keyword planner was used to study the search volume for total stations and terrestrial laser scanners worldwide from 2015-2018 (see Figure 2).

SEARCH VOLUME FOR TOTAL STATIONS AND TERRESTRIAL LASER SCANNERS

Interestingly, the search volume for total stations and terrestrial laser scanners has stayed about the same in the last three years. For total stations there was a 15% increase in search volume from 2015 to 2018. For terrestrial laser scanners there was a 7% increase in search volume from 2015 to 2018. Based on the market growth of total stations and terrestrial laser scanners this search volume growth is lower than expected when considering the overall market growth. One explanation for this could be that the market is already well established with an extensive dealer network worldwide. In other words, interested buyers could already receive enough information about total stations and terrestrial laser scanners from manufacturers and dealers.

PROFILE OF TYPICAL TOTAL STATION AND TERRESTRIAL LASER SCANNERS USERS

User surveys show that *Geo-matching* is primarily used as an information source and is important for product research. On *Geo-matching*, product specifications can be compared, users can read case studies/watch product videos and can contact product manufacturers directly. The user behaviour provides interesting quantitative information and can show general trends. But the types of contact requests made through *Geo-matching* provide even greater insights into how, and for what purposes, total stations and terrestrial laser scanners are used. The enquiries range from major organizations like national armies, universities, surveying and mapping companies, and precision agriculture service providers to large engineering and mining companies worldwide. A notably large number of the enquiries come from the Asia-Pacific region, which is in line with market research.

GEOGRAPHICAL DISTRIBUTION OF GEO-MATCHING USERS

Market research states that the market for total stations and terrestrial laser scanners will grow the fastest in the Asia-Pacific region the coming years. *Geo-matching* user statistics support these claims, but the number of users viewing total station pages, particularly from India, is much higher than expected.

GEOGRAPHICAL DISTRIBUTION OF TOTAL STATION USERS

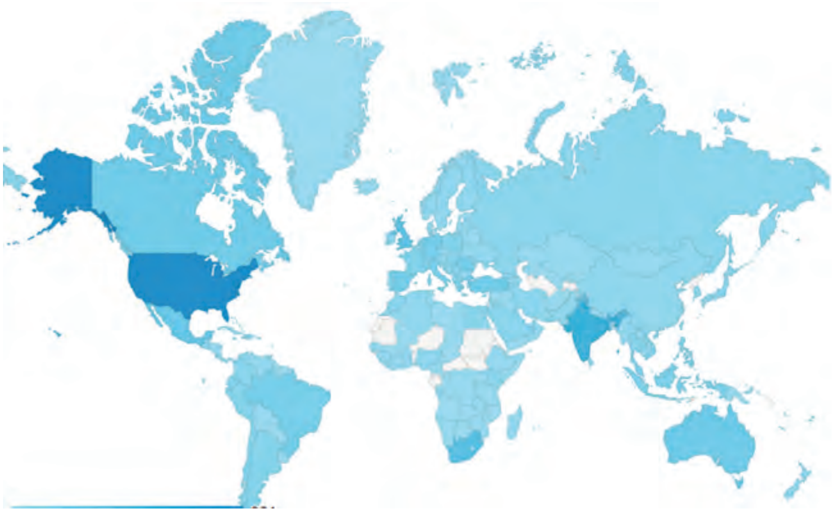
The Asia-Pacific region, and India in particular, is by far the biggest group searching for total stations on *Geo-matching* (58% from Asia-Pacific, 14% from the Americas, 13% from Europe, 12% from Africa and 2% from Oceania).

GEOGRAPHICAL DISTRIBUTION OF TERRESTRIAL LASER SCANNER USERS

Market research identifies North America as the dominant region in the market for terrestrial laser scanners, followed by Asia-Pacific and Europe. It is interesting to see that the *Geo-matching* user profile is in line with this. Most users are from the American regions (29%), followed by Europe (28%), Asia (28%), Africa (11%) and Oceania (3%).

CONCLUSION

The growing construction sector worldwide, the transition towards digitalization, and the increasing role of BIM provide great opportunities for the geospatial sector. Surveying professionals are very familiar with geospatial data and they can leverage their



▲ *Figure 4: Regional distribution of* Geo-matching *users looking for terrestrial laser scanners in 2018.*

skills in 3D data management, modelling and visualization to support the 'design, build and operate' processes that lie at the core of BIM. To support BIM processes, surveying professionals will need to use a mix of advanced geospatial technologies such as aerial and terrestrial photogrammetry and Lidar. Traditional ground survey equipment, such as total stations and terrestrial laser scanners, will however remain key components of any building project. Terrestrial laser scanners are still the connection point between geomatics and BIM because point clouds are very important for creating building information models – especially for interior models.
Market research states that the Asia-Pacific region will invest over the coming years in large infrastructure projects, smart cities and advanced 3D modelling technology. These investments will drive demand in the geospatial market as a whole, and the total station and terrestrial laser scanner markets will also benefit from the geospatial market growth.

The market research findings are supported by *Geo-matching* user data. The Asia-Pacific region is the largest market for total stations and terrestrial lasers scanners and this market is still expected to grow. On *Geo-matching*, 50% of the total stations pages are from India and Bangladesh. For terrestrial laser scanners pages, 25% of views come from India and Bangladesh. *Geo-matching* is primarily used for product research, so the strong interest in the Asia-Pacific region could be a clear indicator of a growing market there in the coming years. ◀

This article is based on a combination of various sources to provide general trends and insights related to total stations and terrestrial laser scanners. For more research data and/or a personalized report, please contact Sybout Wijma (sybout.wijma@geomares.nl).

FURTHER READING:

www.gim-international.com/content/article/bim-a-new-model-for-surveyors
www.gim-international.com/content/article/bim-the-new-gis-for-the-industry
www.marketsandmarkets.com/PressReleases/total-station.asp
www.marketsandmarkets.com/Market-Reports/terrestrial-laser-scanning-market-3652955.htmls
www.gim-international.com/content/article/total-stations-the-surveyor-s-workhorse

Amuse Oneself

Amuse Oneself (AOS) succeeded in the commercialization of the world's first Lidar for multi-copter drone in 2013, and has developed various aerial survey equipment, drones, software applications and web services since then. AOS not only develops various technologies to increase the utilization of industrial drones, but is also focused on educating users in drone-operation safety and techniques to improve survey results. In 2018, AOS developed ground-based and underwater Lidar with a green laser as a member of the 'Revolutionary River Management Project' founded by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MILT). The company also succeeded in measuring surfaces below water. The results were presented at the 'Future Investment Convention' chaired by the Japanese prime minister. The 'Green Laser Lidar' will be available from April 2019.

www.amuse-oneself.com/en

CHC Navigation

Make your work more efficient

CHC Navigation designs, manufactures and markets a wide range of competitive and reliable GNSS receivers and provides complete positioning solutions for surveying, construction, GIS and marine applications in more than 100 countries. CHC is today one of the fastest-growing manufacturers and providers of GNSS products and solutions, developing a significant international presence and employing more than 800 professionals worldwide. CHC has been providing thousands of advanced GNSS receivers globally, combining high performance and innovative features – all at an extremely affordable price. Quality is at the forefront of CHC's philosophy. CHC received ISO 9001 certification from the International Standards Organization applying to all aspects of CHC's development and manufacturing work, from initial design through to delivery of final products to customers. CHC's GNSS receivers are widely used in all regions, from the Americas to Europe, Middle-East, Africa and Asia-Pacific. CHC's international partner network brings dedicated and professional support to end users, regardless of where they are located in the world.

www.chcnav.com
+86 21 54260273
sales@chcnav.com

ComNav Technology

SinoGNSS® By ComNav Technology Ltd.

ComNav Technology is an original equipment manufacturer (OEM) that develops and manufactures GNSS OEM boards, receivers and solutions for high-precision positioning applications worldwide. Its technology is already being used in a wide range of applications such as surveying, construction, machine control, agriculture, intelligent transportation, precise timing, deformation monitoring and unmanned systems. Backed by its team dedicated to GNSS technology, ComNav Technology provides an extensive range of futureproof GNSS products.

www.comnavtech.com
+86 21 64056796
sales@comnavtech.com

SXBlue GPS

Geneq has been developing and manufacturing the popular SXBlue GPS family of GNSS receivers since 2003. With revolutionary technology, the company's mapping-grade receivers are the first to achieve sub-metre accuracy in real time without post-processing. The iSXBlue is the world's first GNSS receiver that connects via Bluetooth to any smartphone, PDA, tablet or notebook. Powered by its 372 channels, the SXBlue Platinum is the ultimate survey-grade GNSS receiver designed for RTK centimetre accuracy with any GIS application, including ESRI Collector and Survey 123. You can now have the whole centimetre real-time solution with Geneq's new CORS base station, the Net20 Pro. According to the company, the new SXBlue Premier is the most cost-effective GNSS receiver on the market today. Geneq also offers an extensive accessories catalogue for all of its receivers.

www.sxbluegps.com
+1 514 354-2511
info@sxbluegps.com

Geo-allen

Geo-allen Co. Ltd. was founded in 2002, in Suzhou, Jiangsu Province, 80km away from Shanghai. Over the years, Geo-allen has grown to be a world-famous company with an R&D team, a trading department, manufacturing workshops and an aftersales-service team. With the DNV's ISO9001 certificate and policies of best service/best quality/best prices, Geo-allen is gaining more and more recognition in its field. The company never stops expanding and developing. Its products now include UAVs, GNSS devices, total stations, theodolites, auto levels, laser instruments and all kinds of accessories. Geo-allen also holds several approved patents for products that it has designed, and is in the process of applying for more. In 2019, Geo-allen will be attending Intergeo in Germany. With the company's goal of Punctuality, Quality, Rigour and Service (P/Q/R/S), Geo-allen is looking forward to becoming more involved in the development of the Belt and Road Initiative as part of its vision of an even more beautiful future.

www.geoallen.com
+86 512 68026320
geoallen@vip.163.com

Hexagon

Hexagon is a global leader in digital solutions that create autonomous connected ecosystems (ACEs), a state where data is connected seamlessly through the convergence of the physical world with the digital, and intelligence is built in to all processes. Hexagon's industry-specific solutions leverage domain expertise in sensor technologies, software and data orchestration to create 'smart digital realities' that improve productivity and quality across manufacturing, infrastructure, safety and mobility applications.

Hexagon (Nasdaq Stockholm: HEXA B) has approximately 20,000 employees in 50 countries and net sales of approximately €3.5bn. Follow Hexagon on social media: @ HexagonAB.

www.hexagon.com
+46 8 601 26 20
info@hexagon.com

Hi-Target

Hi-Target International Group Ltd. acts as the holding company for all investment, mergers and acquisitions in both branding and technology to ensure the corporate vision of providing the best available solutions in the area of geospatial information technology. It is Hi-Target International's corporate goal and vision to provide the best available complete solution to enhance the user interface and experience through its investment in research & development as well as global partnership alliances to bring clients the solutions to enhance their productivity in the field. Hi-Target International will continue to develop products and technologies to meet the ever-increasing demands of the geospatial arena and strives to be the best in its field with solutions for areas such as survey & mapping, GIS, Lidar and laser scanning, unmanned aerial vehicles and solutions, machine control, precision agriculture, hydrographic and oceanology.

www.hi-target.com.cn
+86 20 2288 3944
sales@hi-target.com.cn

MicroSurvey

MicroSurvey has been creating software solutions for land surveyors, accident reconstructionists, forensic specialists, engineers and construction professionals for over 30 years. Its software solutions are helping provide industry professionals the tools they need, in over 120 countries around the world. Recognized worldwide as the best least squares adjustment software on the market, STAR*NET sets the standard as the easiest, most widely used and respected least squares software with the most understandable results. MicroSurvey CAD offers a complete, cost-effective desktop survey and design program designed for surveyors, enabling them to perform standard surveying calculations and create high-quality 2D and 3D deliverables more quickly and easily than those using more complex, non-survey-centric applications. They can even work with point clouds, Lidar and photogrammetric data.

www.microsurvey.com
+1 800 668 3312
corporate@microsurvey.com

Phase One

Phase One Industrial is a market leader in research, development and manufacture of specialized industrial and airborne cameras, aerial imaging systems and software for flight planning, management, image capture and processing as well as a ruggedized powerful controller. Its software solutions include iX Plan, iX Flight and iX Capture which allow quick and easy planning and lighten the workflow for operator, pilot and image processor. The 50MP-190MP cameras offer reliability and versatility for users looking for a full-featured medium-format aerial camera. Its systems (RGB, CIR, NIR and 4-Band) provide a full solution from flight planning to image delivery. Complete systems offer easy integration into existing or new setups, manned or unmanned, and are compatible with multiple flight management systems and GPS receivers. Phase One Industrial's solutions are specifically designed to meet the unique needs of aerial and industrial photography professionals, offering unmatched performance, reliability and accuracy in low-weight and cost-effective systems. Applications include mapping, inspection & monitoring, forestry, vegetation & agriculture, utilities and more.

industrial.phaseone.com
industrial@phaseone.com

Racurs

Racurs has a 25-year history of success on the Russian and worldwide geoinformatics markets. Ever since its foundation in 1993, the company has been developing innovative mapping software for processing aerial, space and terrestrial imagery. The flagship product PHOTOMOD was one of the first digital photogrammetric systems on the market that was designed to work on off-the-shelf PCs. Today PHOTOMOD is the most popular digital photogrammetric software in Russia and well-known all over the world. The main Racurs business activities include the development and further integration of PHOTOMOD into Russian and international markets, photogrammetric production services using both airborne and satellite imagery, R&D in the field of RSD processing software, methods and algorithms, and remote-sensing data distribution in Russia and the CIS countries. Racurs has been an ISPRS Sustaining Member since 1998 and a Special Committee I2AC Member since 2016. Racurs is the organizer of the well-known International Scientific and Technical Conference, 'From imagery to digital reality: ERS & Photogrammetry'.

www.racurs.ru
+7 495 720 51 27
info@racurs.ru

RIEGL

RIEGL is a leading international provider of cutting-edge technology in airborne, mobile, terrestrial, industrial and unmanned laser scanning solutions for a wide range of applications in surveying. Worldwide sales, training, support and services are delivered from RIEGL's headquarters and other offices in Vienna, Salzburg and Styria in Austria, as well as from its offices in the USA, Japan, China and Australia and by a worldwide network of representatives. RIEGL has been producing Lidar systems commercially since 1978 and focuses on pulsed time-of-flight laser radar technology in multiple wavelengths. The company's core 'smart waveform' technologies provide pure digital Lidar signal processing, unique methodologies for resolving range ambiguities, multiple targets per laser shots, optimum distribution of measurements, calibrated amplitudes and reflectance estimates, as well as the seamless integration and calibration of systems. RIEGL's various 3D scanners offer a wide array of performance characteristics and serve as a platform for continuing 'Innovation in 3D' for the laser scanning industry.

www.riegl.com
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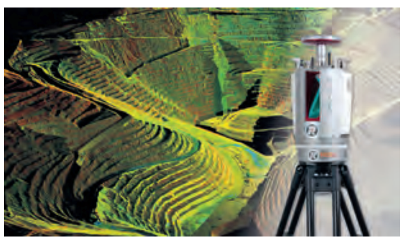
office@riegl.com



Satlab Geosolutions

Satlab Geosolutions is a Swedish global satellite positioning solutions company with offices strategically located around the world. Founded by a group of passionate and pioneering engineers, with a total of more than 40 years of experience in the GNSS industry, the management team is made up of veteran industry experts who value customers' needs. Focusing on research and development, the Satlab Geosolutions team works around the clock to create innovative products for surveying professionals across the globe, providing superior complete solutions. At Satlab Geosolutions, they pride themselves on creating solutions with Swedish engineering and technology. They ensure that all their products meet their rigorous quality checks and assurance, delivering Swedish innovation. The moment users power up the technology for their work, they can rely on solutions that are designed and engineered in Sweden.

www.satlab.com.se
info@satlabgps.com

SBG Systems

SBG Systems is a leading supplier of inertial motion sensing solutions. The company provides a wide range of inertial solutions from miniature to high accuracy. SBG inertial navigation sensors deliver roll/pitch, heading and GNSS position. Combined with cutting-edge calibration techniques and advanced embedded algorithms, SBG Systems' products are ideal solutions for surveying applications whether they are aerial, marine or land-based. The company offers three product lines, each at different level of accuracy and size. The Ellipse 2 Series are miniature inertial sensors reaching amazing performance for the size/weight/power consumption ratio. The Ekinox 2 Series is an advanced inertial system showing a smart balance of size, accuracy and price. The Apogee Series are high-accuracy inertial navigation systems, designed for demanding applications. Qinertia post-processing software completes the offer. This full-feature software gives access to offline RTK corrections, and processes inertial and GNSS raw data to enhance accuracy and secure the survey.

www.sbg-systems.com
+33 1 80 88 45 00
sales@sbg-systems.com

SOUTH

Thanks to 30 years of rapid development, South Group ranks as a dominant force in the global geoinformation industry. One of its key roles is as a leading manufacturer; its factory produces total stations, electronic theodolites, GNSS receivers and all types of survey accessories. On the basis of its huge manufacturing volumes of conventional survey equipment, the company has stepped into an era with higher-end solutions for the ever-changing needs of the geospatial community such as UAV photogrammetry, mobile laser scanning, indoor mapping navigation, railway engineering works and a variety of GIS applications. As number one in the top 100 enterprises in China's geoinformation industry, the company is committed to being a world-class survey equipment manufacturer and web-GIS solution provider. With more and more cutting-edge yet affordable products and solutions, the world market would benefit a great deal from this Chinese giant in terms of quality packages and services at the international level.

www.southinstrument.com
www.southsurvey.com
+86 20 23380888
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Teledyne Optech

With over 40 years of experience, Teledyne Optech is dedicated to the development, manufacture and commercial sale of advanced Lidar survey instruments for airborne surveying, shallow-water bathymetry, mobile mapping and terrestrial laser scanning. Teledyne Optech airborne Lidar systems are complete survey mapping solutions with optional tightly integrated cameras and comprehensive workflows for Lidar/camera processing. Application-specific sensor designs, such as Galaxy PRIME for wide-area and mountain surveying, incorporate innovative and unique feature sets with automated processing routines for the efficient collection, processing and output of survey-grade data products. For surveying the near-shore marine environment, the CZMIL Nova maps water depths, even in turbid conditions, and fuses Lidar, RGB and hyperspectral data to create unique and information-dense map products.
Mobile survey solutions include the LYNX system for the collection of high-density datasets with survey-grade data quality from fast-moving vehicles, and the much smaller Maverick sensor for small-vehicle and backpack installations. Both sensors leverage the same automated LMS workflow as that used for airborne operations.
Finally, the Polaris terrestrial laser scanner provides land surveyors with a user-friendly workflow and long-range performance, at an unprecedented price.

www.teledyneoptech.com
+1 905 660 0808

Vexcel

Vexcel Imaging taps into more than two decades of photogrammetry expertise offering state-of-the-art digital camera and sensor systems. The comprehensive aerial camera portfolio provides a wide range of imaging capabilities from wide-area mapping (UltraCam Condor) to nadir (UltraCam Eagle and UltraCam Falcon) and oblique (UltraCam Osprey product line) camera systems. On the terrestrial side are the car-based mobile mapping system UltraCam Mustang and the UltraCam Panther portable 3D reality capture system. The system family is complemented by the fully integrated processing software called UltraMap, delivering exceptional-quality point clouds, DSMs, ortho imagery and 3D-textured TINs. The Vexcel Data Program (VDP) is a cloud-based imagery service that offers an unprecedented highly detailed image collection covering entire states and countries. VDP is already powering the Geospatial Intelligence Center (GIC), an initiative launched by the National Insurance Crime Bureau to provide its 1,100 members with best-of-breed aerial and terrestrial pre- and post-disaster imagery.

www.vexcel-imaging.com
+43 316 849 0660
info@vexcel-imaging.com

Zoller + Fröhlich

Zoller + Fröhlich offers a new generation of laser scanners which allows beginners and professionals to reach new levels in their projects. The Z+F IMAGER 5016 is small and light. The ergonomically streamlined design features a passive cooling system, IP54 rating and two handles for better grip while carrying and during setup. In particular, this makes mounting the scanner on high tripods and overhead applications much easier. Due to innovative developments, the maximum range of the Z+F IMAGER 5016 has been extended to up to 360m (1,180ft) – thus establishing new opportunities and applications. The maximum measurement rate of more than 1 million points/second guarantees highly accurate results, even at long distances. The Z+F IMAGER 5016 includes many powerful features like an integrated positioning system and a high-definition HDR camera which comes with internal LED spots to shed extra light in dark environments for perfect colour imagery.

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Bringing **BIM** Down to Earth

'BIM' is a hot topic in the industry, receiving regular coverage at many conferences, seminars and webinars. A lot of companies predict that it is one of the 'next big things' for the future, and a not inconsiderable number of companies are already working with BIM today. And that's a good thing! But it is perhaps wise to look past the hype and keep our feet firmly on the ground. Let's bring some nuance into the BIM discussion.

BIM stands for 'building information modelling', or perhaps 'building information management'. The best thing about BIM is the 'I', the information, which really comes from inside the models rather than being added from the outside. The bad thing, or perhaps I should say the limiting aspect, is the 'B': building. Most BIM interfaces are designed for houses and other structures because BIM works best for building and construction. BIM has come a long way in that sense.

I do believe in BIM, because it offers enormous potential when we can have a few common, neutral formats for the transfer and conversion of data. In addition, we keep the metadata: the objects themselves not only contain details of volumes, masses and weights but also information about who, why and when. Therefore, a BIM solution not only for facility management (e.g. construction of houses and other buildings) but also for infrastructure and excavation works would increase the general usage of BIM. Hence, we need to bring BIM down to earth. We need to make BIM accessible directly at the time of measuring. When you use your instrument – whether it is a total station, a GNSS receiver or a scanner – you must be able to see the BIM object in your graphic display.

But what is a 'BIM object'? Well, it is probably a solid, or perhaps a mesh. If it is a solid, it has a volume, contains information about material and mass, and carries more information as built-in metadata. You need to see how the solid will be created as you continue measuring, and you need to import information about the measured object into the digital solid data – either by entering it manually, or (preferably) transferring it digitally based on ID numbers, barcodes or RFIDs. When staking out, you should not be forced to create mesh lines from the solid or, even worse, to create line geometry from various forms of solids. Instead, you should be able to select the BIM object/solid and stake it out, preferably also including the 'I' (the metadata from the digital model) in the analogue model: the real thing. I can already see in my mind's eye the RFIDs rolling out from the tripod… or perhaps the metadata will stay on that very exact coordinate in three positions? That would be bringing BIM down to earth.

At Adtollo we develop the survey CAD/GIS system Topocad and have really embraced BIM. We love it! We love the volumes and we have always been in favour of metadata. BIM is ideal for those of us who are working with quantities and volumes. In Topocad, we have included all the tools for creating solids and inputting metadata on objects. This is based on the fact that each solid has a volume, so most of the quantity tools in Topocad end up as solids and BIM data.

We are also playing our part in bringing BIM down to earth by using functions that create BIM objects with volumes and metadata direct from the survey. There are functions for creating piles, surfaces, beams, curbstones, pillars, pipes, cylinders, cubes (LOD1) and buildings (LOD2) directly from the survey, right from the total station or the GNSS. It is fast, and surveying BIM objects actually requires fewer observations than when surveying traditional objects. So we are doing our best to bring BIM down to earth… and to bring earth down to BIM.

▲ *Tomas Sandström.*

ABOUT THE AUTHOR

Tomas Sandström is business area manager at Adtollo, developer of software for surveying, mapping and design such as Topocad and TopoSurv.

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The Alluring Promise of **5G**

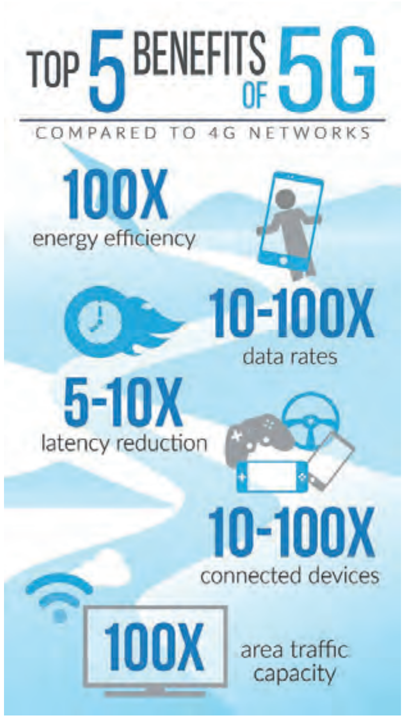
Imagine a world in which high-speed internet is available everywhere. Perhaps you've just ticked skydiving in the Grand Canyon off your bucket list and are keen to share the breathtaking video footage with your family and friends back home (even if they live in a rural backwater). Wouldn't it be great to be able to transfer gigabytes of data to any corner of the planet in the blink of an eye, using just your smartphone? Not so long ago this indeed belonged in the realms of science fiction, but it is now on the horizon and will one day become the new reality. Admittedly this might be a slight exaggeration, but it can do no harm to bring the groundbreaking phenomenon called '5G' to your attention, because it is likely to add a whole new dimension to life as we know it – and that includes the surveying profession.

So what exactly can the geospatial industry expect of 5G? With a potential data capacity of 5G, the next generation of mobile broadband is up to 100 times faster than 4G and 20 times faster than the long-term evolution (LTE) standard for mobile communication. Hence, with its extremely high bandwidth, ultra-low latency (which is by far the biggest benefit) and high-density connections, 5G is set to eclipse 4G and open up a huge array of new applications that are currently impossible using today's network standards. Needless to say, these new use cases will include a multitude of geospatial applications.

Autonomous driving is just one good example of how the surveying profession will benefit from 5G. Thanks in particular to the ultra-low latency, vehicles will be able to constantly receive and also transmit real-time data along their route, including information about roadworks, diversions, driving conditions and congestion. This will also make it possible to update road maps automatically and distribute the updated information to other (autonomous) vehicles in the vicinity.

The collection of cellular-based RTK GNSS data itself is another area that will receive a boost from the rollout of 5G. Currently, office-based staff and fieldworkers can be connected in real time during data capture for operations with a relatively small volume of data, such as GNSS control surveys. With 5G, this can potentially be expanded to include high-volume data such as Lidar or aerial photography, so that the incoming data can be analysed almost simultaneously (and perhaps even automatically). This has numerous advantages; in addition to a significantly less time-consuming and hence less-costly survey process, real-time data analysis also means real-time feedback of meaningful information for faster and more effective decision-making.

Turning our attention to unmanned aerial vehicles (UAVs or 'drones') – or perhaps it is more appropriate to refer to unmanned aerials systems (UASs), since is not merely about the drones, but also about the sensors they carry – these surveying tools potentially stand to benefit most from 5G. In fact, the UAS is a disruptive technology that almost seems to have been waiting for cellular mobile communications and the Internet of Things (IoT) to catch up. The 'dream team' of UAVs, sensors, 5G and IoT holds the alluring promise of facilitating unprecedented mapping and surveying tasks. For example, thanks to its real-time data capabilities, 5G will make it possible for drone flight paths to be altered even during the survey using the real-time-captured data. When combined with the IoT, this could be done from virtually anywhere with an internet connection without even needing a dedicated solution. This combination of platforms, real-time data transmission and the IoT will open up huge potential for the efficient, safe and cost-effective (thanks in particular to labour savings) mapping of urban environments. As a result, we can expect the 'smart city' trend to really take off.



▲ *The top 5 benefits of 5G. (Courtesy: CommScope)*

Another area that could experience tremendous gains from 5G is precision agriculture. Just some examples of possible applications include monitoring crop health, detecting irrigation problems and collecting information on soil variation. 5G will improve the speed, convenience and even autonomy of such activities, thus driving the further adoption of technology in farming and hopefully even helping society to tackle the looming global food shortage.

It goes without saying that we still have some way to go. Although comprehensive rollouts are expected from as soon as 2020 onwards, expert opinions vary on the speed of the 5G expansion over the next five years and it will certainly take much longer before there is truly global coverage. But we are moving ever closer to that dot on the horizon – and 5G is likely to revolutionize the surveying industry long before we actually reach it. ◀

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Quickly scan 3D terrain.
Drone-mounted LiDAR system.

In Flight Alignment
3 min

The lightest in class

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TDOT PLUS : 1.8kg
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Accuracy of ± 50 mm achieved.
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(These values are from evaluation result by Japan Ministry of Land, Infrastructure, Transport and Tourism)

Laser surveying
MAX 27 min per flight*

Preview
3 min

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Automatic processing of optimal baseline analysis in the cloud.
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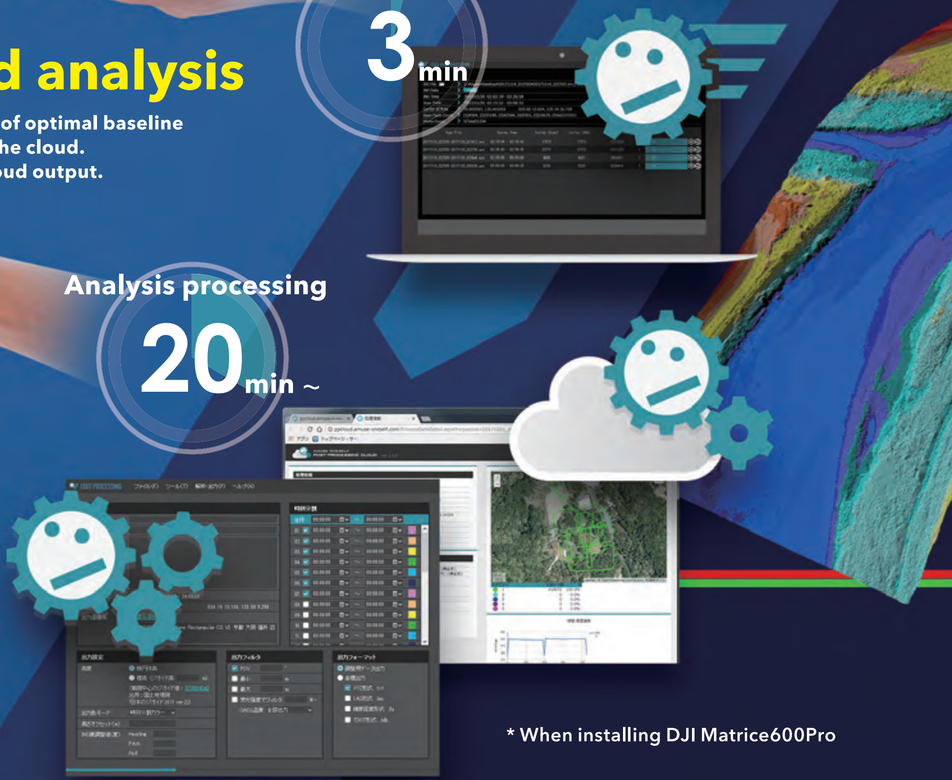
Analysis processing
20 min ~



Attachment

Payload can be mounted onto a general-purpose drone with 3 kg or more.
One-touch desorption (desorption in several seconds).

* When installing DJI Matrice600Pro

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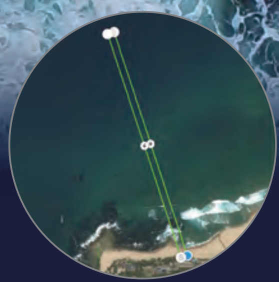
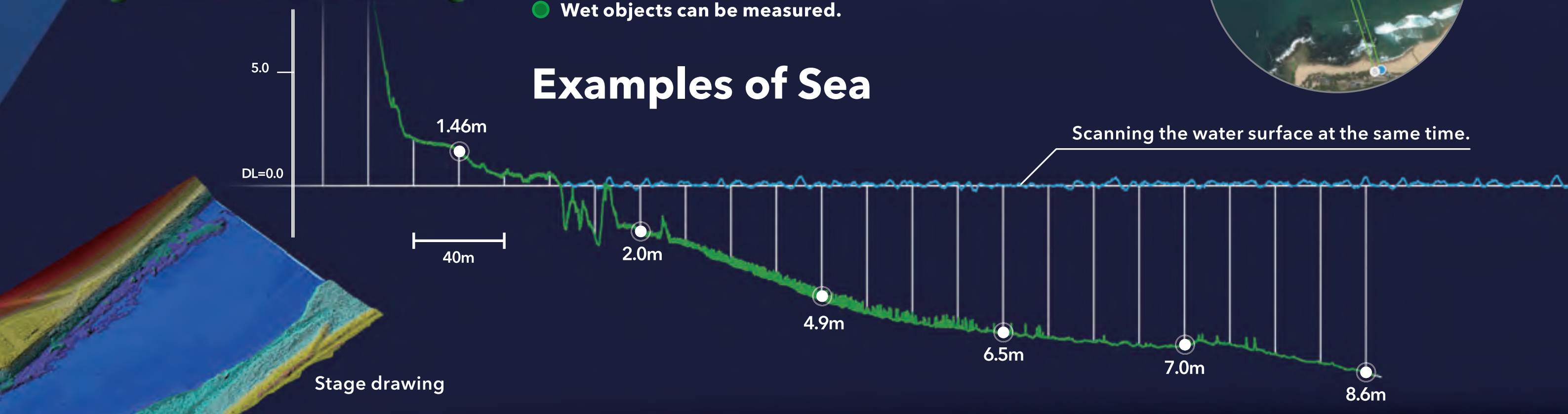
Available in April 2019

- Inherit the performance of TDOT PLUS as it is.
- Scan topographical topography under the water surface.
- Wet objects can be measured.



Examples of Sea



Examples of Rivers

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